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STRUCTURE IN ELECTROLYTIC SOLUTIONS.*

BY

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The foundations of the classical theory of solutions as laid by *Van't Hoff*, *Arrhenius* and *Ostwald* are distinguished by their simplicity and the readiness with which they can be mathematically formulated.

The basis is firstly the Law of Equipartition, according to which every particle, heavy or light, gaseous or in the liquid state, and quite independently of its chemical nature or form, always possesses the same mean energy of translation at a given temperature. On this finally depends the fact first realized by *Van't Hoff* that measurements of osmotic pressure, of freezing point depression, of boiling point elevation, and so on, enable us to determine the number of free particles in solution without it being necessary to take their special properties into consideration.

The second great step was made when *Arrhenius* ventured the suggestion that in those cases where experiment, thus interpreted, revealed more free particles than the molecular formula allowed, there was a dissociation into ions capable of permanent existence. Besides the observation of the above mentioned equilibrium phenomena, whose description and interconnection can be dealt with by pure thermodynamics,

* Read at the Medal Day Meeting, Wednesday, May 19, 1937, by Dr. Charles P. Smyth.

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it was now possible to use the electrical conductivity, which is concerned with irreversible processes, in order to count the free dissolved particles. But at the same time a new variable appeared, namely the degree of dissociation: hence the theory was not quite rounded off until *Ostwald* had applied the Mass Action Law of *Guldberg* and *Waage* to state the dependence on concentration of the equilibrium between molecules and ions.

Wide as was the region that was now made clear, and for all that the new theoretical structure had been shown by *Nernst* to be firm enough for extension into further domains, *one* anomaly soon made itself evident. The more precisely the observations were made, the clearer it became that the behaviour of just those commonest of salts a high percentage of whose molecules dissociate into ions cannot be given a satisfactory quantitative description in terms of the classical laws. For decades no success was reached in dealing with this anomaly of the strong electrolytes, although quite early, with fine perception, *Van Laar* had surmised that here abandonment of the Mass Action Law and consideration of the electrical interionic forces might be able to provide the solution.

The chemist usually has to deal with forces between atoms, which may be very powerful but are only effective over extremely short distances. The Law of Mass Action fits this case: so for example the equilibrium between molecules and atoms in iodine vapour is properly dealt with by this law. But besides these there are other often weaker but at the same time much more far-reaching molecular forces which are not accessible to this treatment. These are the forces which *van der Waals* considered in his equation of state and whose working becomes visible in the liquefaction of gases. Especially strong and extremely far-reaching are the electric forces between ions, obeying *Coulomb's* law. They only decrease in proportion to the square of the separation, and therein lies the peculiar difficulty in handling them theoretically. Thereby the direct use of *van der Waals'* method of treatment is prevented, and this is also the underlying reason why the explanation of the Anomaly of Strong Electrolytes took such a long time.

In setting up an equation of state of real gases after the manner of *van der Waals* it still remains possible to make the first step in such a way that only the effect of a molecule on its nearest neighbour is brought into consideration. The ordinary molecular forces still fall off in proportion to so high a power of the separation that all other molecules can be regarded in good approximation as infinitely remote and so without effect. This is no longer the case when the mutual potential energy of two particles decreases with a smaller power of the separation than the third. When that is the case, it becomes necessary from the beginning to set the consideration of the effect of a molecule on the whole of its surroundings at the head of the discussion.

I first became concerned with this question as the result of a lecture I heard in Zurich on *Ghosh's* theory, which was attracting lively interest at the time. *Ghosh* started from the idea that for example in a solution of sodium chloride the ions acted so strongly on each other that even in solution an arrangement of sodium and chlorine ions was established as in the solid crystal. Only the distance between the ions (and so the lattice constant) in solution was supposed to depend on the concentration in such a way that the ion lattice extended through the whole solution. It must be freely admitted that in fact a tendency to produce such an arrangement must also be present in the liquid, but I consider it impossible that this tendency could be strong enough to bring the lattice-order into real existence. The thermal movement must work much too strongly against it. So I had the problem before me to calculate what arrangement would actually establish itself in nature under the influence of these two opposing tendencies, and how this arrangement could best be defined. My first attempts were concerned with the calculation of the phase integrals, by the evaluation of which every problem of this sort can be strictly solved. Later both *Kramers* and *Fowler* were so far able to overcome the mathematical difficulties that a comparison could be made with the formulation meanwhile arrived at in a different way, and at the same time it could be re-established on a basis free from objection. For me the problem was then too difficult, and I ventured to use an abbreviated method to describe the significant properties

of the arrangement of ions in a solution. For this purpose the idea of the Ionic Cloud was introduced. If one considers an electrolytic solution, for example a solution of sodium chloride, from outside so to speak, then in a spacially fixed element of volume in a time-average just as many positive sodium as negative chlorine ions will be found. Quite different is the picture when the observer is thought of as fixed to one of the sodium ions so that he follows all its movements and observes his surroundings from this moving point. Then he will find that chlorine ions are favoured, especially at shorter distances, and their number in the time-average exceeds that of sodium ions. We can thus speak of a cloud of electric charge, for which every point has in time average a particular charge density, of opposite sign throughout to that of the central ion, but less dense the further the point under consideration is from the centre. The same is naturally true for every ion in the liquid, and this is the structure which must take the place of the crystalline structure pictured by *Ghosh*. Since the ordering force producing the ionic cloud is the simple Coulomb attraction or repulsion, by which in competition with the disordering thermal movement the resultant equilibrium in the mean distribution of the ionic cloud (at any rate in dilute solutions) can only depend on the concentration, the ionic charges, the dielectric constant of the solvent, and the equipartition energy, proportional to the absolute temperature. From these quantities, correspondingly, can be calculated the so called radius of the ionic cloud. One can define this in such a way that the potential energy of an ion with regard to the surrounding ions in the solution is identical with the energy it would have with regard to a single ion of equal and opposite charge at a distance equal to this radius. So it is possible to calculate the electrical work which is involved in the production of a solution. Once this is known, thermodynamics provides all the machinery necessary to deduce the improvement to the classical laws which an allowance for the interionic forces brings about. In this direction, incidentally, an interesting previous achievement had already been made by *Milner*. In a painstaking and difficult investigation he had succeeded in calculating the internal distribution in a solution for a particular case. My

introduction of the ionic cloud was not much more than the provision of an easy short cut with the help of a happy guess. The theory happened to be accused of dealing with completely dissociated solutions; but the accusation was not actually justified since the significant portions of the treatment still remained valid for electrolytes which are only partially dissociated. Naturally however the distinctive nature of the new treatment shows itself most clearly in solutions in which the degree of dissociation is near to 100 per cent. It appears in fact that in many cases *Bjerrum* was right in supposing that total or nearly total dissociation should occur, it now being shown that the apparent incomplete dissociation could be interpreted merely as the result of the interionic forces.

In the elaboration of the theory, soon after beginning, I enjoyed the active and valuable collaboration of *E. Hückel*. An important quantitative result, arising from the particular form of the Coulomb forces, was that the radius of the ionic cloud is inversely proportional to the square root of the concentration. Correspondingly, in small concentrations the influence of the ionic forces becomes particularly large and outweighs all other influences. This is also the reason why, in particular, experiments on extremely dilute solutions have yielded the most important and clearest conclusions about the significance of these forces for the properties of electrolytic solutions.

A second important result is expressed in the statement that not the ordinary concentration, but a sort of weighted concentration determines the size of the radius of the ion cloud. The theory requires that this concentration, which we call the *Ionic Strength* should be computed by first multiplying the numbers of each sort of ions by the squares of their valencies before adding them together. This is the way in which the particularly strong effect of highly charged ions finds its expression.

At the time when Hückel and I first worked on the theory I was not well acquainted with the literature of the subject. It was a great pleasure for us when we found after some time that *G. N. Lewis* had already recognized purely experimentally from a study of electrolyte solutions, firstly the special significance of the square root of the concentration, and secondly

the fundamental role of the Ionic Strength instead of the usual concentration. In America it is unnecessary for me to spend much time in telling how *Lewis*, starting from pure thermodynamics in his fundamental investigation came to give a precise definition to the idea of Activity, and how the purely experimental pursuit and determination of activities led him to his laws. Our considerations now made it possible to visualize how the surroundings and the resulting ion cloud restrict the operation of an ion, so that it is no longer effective in proportion to its simple concentration, but in proportion to its activity.

This is distinguished most clearly in the beautiful experiments of Bronstedt and La Mer on the change of solubility of difficultly soluble salts when foreign strong electrolytes are added to the solvent water. When the ions of the solid phase try to go into solution they must first escape from the crystal lattice, and only the fact that when they enter the water, energy is returned to them by hydration which enables them to dissolve at all in appreciable quantity. Now if the water already contains the ions of a foreign electrolyte an ionic cloud of the opposite sign can immediately form itself around every ion which leaves the solid phase. The ion will thus be pulled into the solution by an additional purely electrical force in much the same way as a charged body is attracted by an electrically conducting plate. The final result is naturally that more ions of the solid phase go into solution. That provides a picture of the effect, which is quantitatively expressed when one calculates the activity of the ions of the difficultly soluble salt in the electrolyte solution, and by how much it has been reduced.

It was clear however from the beginning that the interpretation of the activity of the ions was not enough. The striking behaviour of the electrical conductivity of solutions of strong electrolytes must be explained too. That here also the ionic cloud must yield the key was already clearly indicated by the result, long known but till then incomprehensible, to which *Kohlrausch* had come through his experiments. The molar conductivity of solutions of strong electrolytes at high dilution decreases in proportion to the root of the concentration, and the classical dissociation theory is not in the position to give any reason for this peculiar behaviour. The electric

conductivity is proportional to the number and mobility of the ions. When it is established that on doubling the concentration the conductivity becomes less than twice as great and on the other hand it must be concluded from the thermodynamic behaviour of the solution that the number of ions has doubled and none has fallen out by formation of molecules, then the mobility must have suffered. Hence there arises the problem of explaining how the ionic cloud can hinder the ordered movement of ions in an electric current. This problem was now attacked in association with *Hückel*, and two causes of the sought-for effect were found.

The solvent around every ion is on the average charged with the opposite sign, since it carries the ionic cloud. Consequently under the influence of the electric force which drives the ions themselves in the electric current, on the average an additional force in the opposite direction is exerted on the solvent. In consequence the friction is increased, and as the force on the solvent arises in just the same way as in the phenomenon of electrophoresis, we called this additional frictional force the "Electrophoretic Force."

There is a second and more interesting effect, connected with a property of the ionic cloud which we have not yet discussed. Let us consider a foreign ion suddenly brought into an electrolytic solution: Then around this ion there will be first of all complete disorder. However it exerts electric forces on the surrounding ions and must therefore build up its own ionic cloud: but that requires time, and the electrical density in the cloud will only gradually reach its steady distribution. Keeping this in view let us consider an ion in an electric current, moving, let us say, to the right. On the right of the ion, then, its cloud is always forming, and on the left breaking down again. Remembering the finite relaxation time which we have just discussed, the cloud must always be less dense on the right and denser on the left than corresponds to equilibrium. Since however the charge of the cloud is necessarily opposed to that of the central ion a force directed to the left, that is to say, an increased frictional force, must appear. We called this second force the "Relaxation Force."

It could be shown for both forces that they are proportional to the root of the concentration, and so Kohlrausch's law found its explanation. It must be added that after the investigation was published *Onsager* found that the calculation was not quite without objection. The thermal movement of the Central ion had been left out of consideration and hence the formulae obtained had to be corrected. He did that, and the theory of the conduction of dilute solutions is free from objection since then. *McInnes* was able to show by very neat direct experiments that it is in fact the reduced mobility and not the reduced number of ions which reduces the conductivity of strong electrolytes.

The square root of the concentration is always the sign that the ionic cloud is at work. A characteristic example is shown among others by the observations of *Jones* and *Dole* on the viscosity of highly dilute electrolyte solutions. When Dole came to Europe, in order so to say, to interview us as experts on the square root, that led to the development by *Falkenhagen* of the theory of the influence of the ionic cloud on flow, and thereby to the explanation of the observed regularity.

But it is not enough that a theory explains the experiments that are on hand: It should also predict new ones. That also has occurred.

It has already been said that the ionic cloud needs a finite time to be established. The same is true of the dissymmetry which is present in the case of a steady current and for which the relaxation time is responsible. That also can only gradually develop and disappear. To be sure, calculation shows that the relaxation time is very small: in a solution of concentration 1 millimol per litre it is of the order of magnitude 10^{-7} sec. and becomes still smaller with increasing concentration. However conductivity measurements in fields which change direction 10^{7} times in a second are possible without more ado, since a time of 10^{-7} sec. corresponds to a wave length of 30 m. For such rapid vibrations one expects that the dissymmetry present in the steady state will no longer be able to develop. When that drops out then at the same time disappears the relaxation force, and so a part of the additional ionic friction. Hence we conclude that the conductivity of

solutions of strong electrolytes will rise above its stationary value when the measurements are conducted with a high enough frequency. The experiments undertaken on the grounds of this prediction by various authors, among whom I would like to indicate as the first my then assistant *Sack*, have confirmed the expectations.

Experiment again takes the leading place in another sphere, the question of the validity of Ohm's law. *M. Wien* set himself the problem of measuring conductivities with the highest possible field strengths and worked out a method of making measurements in the very brief time to which on practical grounds the action of the intense field must be confined. He found that in fields in which the ions reach velocities of the order of magnitude 1 meter/sec. Ohm's Law is no longer valid, and the conductivity is greater than in the stationary case. He found further that in strong electrolytes this effect does not rise above a certain limit. Both could be explained by the theory of interionic forces: *Joos* carried out the first calculations on the basis of the ion cloud structure. Here also the decisive factor is the finite relaxation time. If the ions under compulsion of the strong fields move so rapidly that during the relaxation time they have covered distances of the same order of magnitude as the radius of the ionic cloud, then obviously the ionic cloud can never properly develop. But if the ionic cloud is lacking, both additional frictional forces disappear likewise. In the limit for very strong fields the ions must have the same mobility as at infinite dilution. Hence the conductivity increases with increasing field strength towards its value at infinite dilution as a limit.

In order to keep this sketch within reasonable bounds I have had to confine myself to the beginnings of the unfolding of the theory. Much of importance had to remain unmentioned. So nothing was said of the interesting work of *Gronwal* and *La Mer* and more recently of *Scatchard* whose object is to bring the behaviour of concentrated solutions also within the theory's grasp. The entire new development, which we principally owe to *Kraus*, *Fuoss* and their collaborators, in the sphere of solvents with smaller dielectric constants, in which *Bjerrum's* idea of electrostatic association of ions comes into its own, had to remain unmentioned. The

interesting experiments of *Wien* on the change of dissociation of weak electrolytes by strong fields (for so, according to *Onsager*, must we interpret the Wien effects in this case) could not be discussed. The promising and far-reaching formulations of *Kirkwood* from which it appears possible that it may not be long before we possess an unobjectionable and systematic statistical mechanics of electrolytic solutions were likewise passed over in silence. I want to emphasize that these investigations were not omitted because I think they are less important. The very reverse is true.

Going through the names which have been mentioned here, one finds that many nations (8 according to my count) have worked together, and the share of the United States is a large one. I am particularly pleased that the task set me of talking about my own work has given me the opportunity to acknowledge the blessings of international co-operation in the field of science.

V.
19

EXPLORING THE STRATOSPHERE FOR NEW ELECTRICAL EFFECTS.*

BY

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I know of no more coveted honor that could come to me than to be the recipient of the Franklin Medal, for the name of Franklin has always been one to conjure with in the Millikan family. My great grandfather, Alexander Millikan, married Hannah Franklin, my grandfather's name was Daniel Franklin Millikan, my father's name Silas Franklin Millikan, my brother's and my son's names, Max Franklin Millikan. There has always been a tradition in the family passed down from Hannah Franklin that her family, which lived in Massachusetts, had some sort of a blood relationship to the Benjamin Franklin family though I have never been able to verify the claim. Wholly apart from the tradition, however, no small part of the inspiration for my own work goes back to the great Philadelphian.

Franklin's two great scientific contributions to knowledge and its application to human life consisted (1) in perceiving more correctly than anyone else had done before, or did for a hundred and fifty years thereafter, the nature of electricity itself and its relation to matter, and (2) in applying that insight to the study and the control of the most terrifying of natural phenomena—the lightning.

Franklin's conclusion that positive and negative electric charges must inhere in the very nature of the atoms of matter themselves, the atom being neutral when the electricity is present in normal amount but showing a charge of one sign when the electricity is present in excess, and a charge of the opposite sign when the electricity is present in less than its normal amount, and his even more remarkable conclusion that electricity must be granular in structure, his own words

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being: "The electrical matter consists of particles extremely subtle, since it can permeate common matter even the densest with such freedom and ease as not to receive any appreciable resistance"; these are ideas which have inspired much of my own work on the electron as well as that of many others and for the validity of which I have had the good fortune to bring to light some little justification.

But it is in the second field of Franklin's activities, namely that of exploring the earth's atmosphere for new electrical effects and insights that I have been working in recent years, and it is in this field that I hope today to be able to present to The Franklin Institute some newly acquired knowledge as to the electrical behavior of matter. Franklin's explorations into the upper atmosphere took him up only as far as he could reach with a kite. Further the practical application of his knowledge of electrical behavior to the protection of buildings, while world wide in its beneficient effects, reached no farther upward than to the low lying thunder clouds which manufactured the lightning, from the disastrous effects of which he sought to protect mankind and sought successfully.

The researches with which I propose to deal herewith reach up on the other hand to the very top of the atmosphere, or more accurately so near to the top that between 98 per cent. and 99 per cent. of the atmosphere, by weight, has been left behind. Also the trend of the phenomenon studied is so clearly revealed that little of importance can be learned by going still higher. The reason for making these studies is found in the fact that apparently in no other way can the law of absorption of electrons or photons of enormous incident energy—up to twenty billion electron volts—by the nuclei of atoms be definitely determined. This is an exceedingly important point in the extension of our knowledge of Franklin's old problem of the electrical constitution of matter, or better of the relation between electricity and matter, and I hope a significant forward step has been taken in the results herewith presented.

In order to make the problem quite clear let me review some aspects of our progress since 1911 in the investigation of the electrical constitution of the atom. By 1911 the negative electron had definitely taken its place as a constituent of

all atoms. It had been taken out of the atom, isolated on an oil droplet and its charge reasonably accurately determined a year earlier than this, and at least a decade earlier its existence had been proved and its mass or inertia determined by J. J. Thomson and others at about one two-thousandth that of the hydrogen atom.

It was in 1911 however that there first appeared on the scene the present nuclear atom in accordance with which all of Franklin's positive electrification is found in a nucleus which carries practically the whole weight, as well as the whole positive charge of the atom, while the neutralizing negative—Franklin's "normal amount of electricity" is carried by a definite number of negative electrons—Rutherford's *atomic number* of the atom—which circulate about the nucleus and by their ability to become detached from it impart to the atom its valencies.

During the next dozen years the mechanism by which these extra nuclear electrons receive and emit radiation was the all absorbing problem of atomic physics. The photo-electric equation, the Bohr atom, the spectroscopic laws, both in the optical and the x-ray fields, the photon theory of localized darts of radiant energy, the mechanism of the production of fluorescent and of *general*, or *impulse* x-radiation, were all worked out in this dozen years and by 1925 the nuclear atom with its positive nuclear charge varying from 1 in hydrogen up to 92 in uranium, its atomic weight varying from 1 to 242 and its extra nuclear shells of negative electrons varying, like the nuclear charge, from 1 up to 92 was a familiar figure in all physical laboratories and its characteristic modes of behavior had become reasonably well understood.

Then cosmic rays began to break into the consciousness of the world of physics, and with them came the suggestion of the possibility of pushing our knowledge beyond the field of extra nuclear physics and into the very heart of the atom—the nucleus itself. For although Rutherford in 1919 had proved that protons could be knocked out of certain atoms under the bombardment of x-rays from radium, the energies required for nuclear disintegrations were at that time thought to be so high that little hope had been expressed of going much farther with alpha-ray bombardment than Rutherford had

already gone. But here, in the cosmic radiation, was an agency that certainly had a very much greater penetrating power, and therefore presumably a very much greater energy than any agency existing on earth.

The *first* evidence for the existence of a penetrating radiation coming in from outside the earth had been brought to light in 1910, 1911 and 1913 respectively by Gockel in Switzerland, Hess in Austria and Kolhörster in Germany, the first explorer by taking up an electroscope in a manned balloon to a height of 15,000 feet, the second to 17,000 feet, the last to about 30,000 feet. All of these found the electroscope's rate of discharge at the altitude reached greater (the last two much greater) than at the surface, thus showing definitely that the rays could not originate in the earth, but must either have come in from outside through the atmosphere, or else have their origin in radioactive materials distributed throughout the atmosphere.

The first stratosphere flight carrying up electrical cosmic ray measuring instruments was made by Millikan and Bowen in April 1922, on purpose to test this point. These experimenters anticipated that if the rays came in from outside the rate of discharge of their electroscope would increase exponentially to the top of the atmosphere. It actually reached an altitude of 55,000 feet—well into the stratosphere—but the rapidity of discharge failed to continue to rise up to that altitude at the rate found by Hess and Kolhörster in their lower flights, thus raising doubts in the minds of the workers as to whether the rays came in at the top of the atmosphere or not.

In 1925 however Millikan and Cameron by finding electroscope discharging effects persisting down to depths of some fifty feet below the surface of two high altitude snow fed lakes (Muir Lake and Arrowhead Lake, the first in the High Sierras, California, the second in the San Barnardino mountains, California) brought forth what they regarded as unambiguous evidence that the rays originate very far outside the earth, in the cosmos, and hence these authors applied to them the name of cosmic rays. Kolhörster too from experiments made in 1923 in an Alpine glacier drew the conclusion that he had at least "established the existence of a hard

gamma ray having an absorption coefficient about 1/10th that of the hardest known gamma ray." These conclusions are now universally accepted.

Up to 1930, however, the only way anyone had to estimate the energy of the incoming cosmic rays was by assuming that the relations between penetrating power and energy, experimentally established in the gamma-ray range of energies, hold also for the more highly penetrating cosmic rays, when in this year (1930) Dr. Carl Anderson and I devised a direct method of measuring the energy of the cosmic rays with the aid of a very powerful magnetic field, we found that the former computations of energy made by all of us were grossly incorrect, for the laws which we used (notably the Klein-Nishina law) had been worked out both theoretically and experimentally for extra nuclear absorption, no one having thus far developed any knowledge whatever of nuclear absorption.

It was in that same year (1930) that Chao in the Norman Bridge Laboratory first showed that a strong nuclear absorption of gamma rays sets in in lead at an energy of the incident gamma rays of about two million electron volts, and within three years of that time Oppenheimer had worked out a theory of nuclear absorption the utility of which had been experimentally tested and found satisfactory by Lauritsen and his pupils in the range of photon-energies in which they were able to work with their superpower X-ray tubes; namely, up to some fifteen million electron volts. This theory was extended by Bethe and Heitler to cover the case of the nuclear absorption of high energy electrons as well as of photons. The elements of this latter theory are as follows. When high speed electrons impinge upon a target of any kind, in view of their extreme lightness and their charge they experience very sudden decelerations because of the electrical constituents of the atoms through which they try to pass, and "impulse radiation" of the electro-magnetic sort results. This is the so-called "brehms-strahling" theory, dating from about 1912, of the origin of the general, or scattered X-radiation emitted from the target of an X-ray tube. Both experiment and theory show that a larger and larger fraction of the energy of the bombarding electrons is transformed into such general or impulse radiation, as the bombarding energy increases.

Above a few hundred thousand volts the characteristic X-rays emitted by a target become quite negligible in comparison with this impulse radiation.

Now in 1933 it was first proved unambiguously by Anderson & Neddermyer and the Joliot-Curie pair that when a two and a half million volt photon impinges upon a nucleus the energy is transformed in the impact into a positive-negative electron pair. The Bethe-Heitler theory of the absorption of high speed electrons by the nucleus of an atom assumes that the first act in the absorption of such high speed electrons consists in the transformation of much of the incident energy into impulse radiation, photons, that these photons then produce by further impact with nuclei, electron pairs as first suggested in Blacket's paper of April 1933, that these pairs produce in turn new photons, and so on until the whole of the incident energy thus becomes successively degraded into photons and electrons of lower and lower energy until it is all finally frittered away through the ionizing effects of the immense progeny of low energy electrons that are ultimately formed.

This theory worked beautifully in the low energy range—up to fifteen million electron-volts in which Lauritsen first tested it. It also furnished a very satisfactory qualitative explanation of the phenomenon of cosmic ray showers, but it required for this explanation an exceedingly high rate of absorption of both photons and electrons especially in heavy substances like lead.

This high rate of absorption was also demanded by the theory of the probability of an impact between a nucleus and an incident photon or electron. Indeed when Oppenheimer and Plesett and Bethe and Heitler applied the theory to the interpretation of the cosmic rays they all came to the conclusion that the law of absorption given by the theory for both electrons and photons could not be applicable to energies of the type found in the cosmic rays, because they computed that even a ten billion volt electron or photon could not get through more than say four centimeters of lead or two meters of water, while we actually find cosmic rays going through ten meters of water in getting down to sea level and revealing traces of their influence in lakes at depths of more than one hundred meters of water.

The experiments of Bowen, Millikan and Neher at the very top of the atmosphere have just re-solved this difficulty, for they show that even the electrons up to twenty billion volts of energy, such as alone can get through the earth's magnetic field in the neighborhood of the magnetic equator, are actually absorbed exceedingly rapidly in the very upper layers of the atmosphere. Indeed our recent flights up to more than 98 per cent. of the top of the atmosphere made both at San Antonio, Texas (Mag. lat. 38.5° N.) and at Madras, India (Mag. lat. 3° N.), show that the total hemispherical cone of incoming cosmic rays, whatever their nature, is so rapidly absorbed that these rays are producing their maximum ionization before they have penetrated one-tenth of the way through the atmosphere and that from that point down their effects fall off exceedingly rapidly and essentially exponentially. Further the difference between the *foregoing two curves* shows unambiguously just how incoming electrons of a mean energy of ten billion volts are absorbed. They are shown to penetrate only one-twentieth of the way through the atmosphere before they are found producing their maximum ionization of 160 ion cc./sec. They then fall off so rapidly that at five meters of water, or half way through the atmosphere, they are producing less than ten ions per cc./sec. and at sea level only 0.3 of an ion per cc./sec.

The curve near the top follows sufficiently closely the Bethe-Heitler law to make it permissible to conclude that the main mechanism of absorption in that part of the atmosphere is that pictured (see above) in that theory. These experiments may then be considered to have established the law of nuclear absorption of both electrons and photons by the nuclei of the higher atoms up to the stupendous energies of about twenty billion electron-volts. They show further in general that practically all incoming cosmic rays are absorbed in the very upper layers of the atmosphere where this absorption generates practically all the secondary effects which are observed at sea level and below. These are undoubtedly in the main merely secondary influences or splashes perhaps of very diverse sorts, some penetrating, some easily absorbable, which find their source in the absorption in the upper layers of the atmosphere of the great bulk of the incoming cosmic rays.

Dredging an Island from Davy Jones.—(*The Excavating Engineer*, Vol. XXXI, No. 6.) Magnitude excepted, there has been nothing famously new or original about dredging 25,000,000 cubic yards of material from the bottom of San Francisco Bay to form a 400 acre rock-walled island for the Golden Gate International Exposition in 1939 and thenceforth for permanent use as a municipal airport. It has been a matter of plugging along and pumping away, with as many as nine big dredges on the job simultaneously to produce an island level at 13 feet above mean lower water where before were shoals ranging from two to 26 feet below. In February of 1936 the U. S. Engineer Department and the Exposition Department of Works settled down to build an island 5,520 feet long by 3,400 feet wide. It was to be linked to Yerba Buena Island, midway point of the San Francisco-Oakland Bay Bridge, by a causeway 900 feet long and 110 feet wide. Since then cutters have attained brilliant polish, spuds have snapped in ground-swells, and the job will be finished in July, this year. The fill was brought up to grade in successive levels, beginning at the south end of the island area and working northward; this method squeezed fine materials out of the open end of the fill, so that 25,000,000 yards of materials were handled to obtain the 20,000,000 yard firm sand fill within the rock seawall. This wall, over a lineal distance of 17,760 feet including the causeway, contains 287,000 tons of rock fill brought from quarries surrounding the Bay in units with specified classifications ranging from three pounds to three tons. During the World's Fair on the island in 1939, this "virgin territory for Uncle Sam" will be host to an anticipated 20,000,000 visitors and will concentrate on "made land" the evidences of man's progress, including comprehensive displays of engineering and contracting equipment and achievement.

R. H. O.

V. 19

COUNTER GRAVITY DIE CASTING OF HIGH MELTING-POINT METALS.*

BY

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It is particularly satisfying to me to have the privilege of discussing before the Franklin Institute the scientific principles involved in the art of casting metals. I propose to show that it is perfectly practical to make sound and accurate die castings of iron in iron moulds. I have developed commercially practicable means of achieving this result by forcing molten metal "uphill" by pneumatic pressure into the bottom of a die in preference to the old method of pouring or cascading it "downhill" with gravity.

The historical background is greatly enriched by the fact that this subject commanded the expert interest of the immortal Benjamin Franklin to such an extent that he might be called a pioneer in precision type-metal casting in America.

The parent idea found its most natural expression in supplying the need for accurate, clear-cut type in repetitive quantities where each reproduction of each letter of the alphabet had to conform very exactly to its master design.

To engrave each individual type by hand was a tedious and expensive process: to avoid this, painstaking care could well be expended on engraving a die or cavity which was to mould, without injury to itself, an indefinite number of reproductions. Because of its low melting-point, type metal could not injure the die, and at a very early stage in the art, it was found that antimony would combine with lead to give hardness, to eliminate shrinkage, and to reduce the melting point. Type founding, therefore, was early successful when poured by hand and later was quite readily adapted to pressure casting against gravity in automatic machines.

The Lanston Monotype and Merganthaler type casting and type setting machines are fine examples of the feasibility

* Presented at a meeting held Thursday, March, 4. 1937.

and advantage of placing metal moulds in communication with a molten metal container and applying pressure to force the molten metal positively into the die cavity.

Up until 1906, the art of forcing molten metal into metal moulds was, so far as I know, confined entirely to metals having much in common with type metal in that their melting points were all well under 700 degrees F., and they had little or no shrinkage.

When in 1906 I was consulted as to the feasibility of die casting the more generally useful metals of higher melting-points and higher shrinkages, one then "skilled" in the foundry art declared categorically that it was and always would be impossible because, self-evidently, when metal cools it shrinks and in a sand mould the crumbling sand will yield and permit the shrinkage to take place without strains in the casting, whereas in the metal mould the contraction of the casting could not crush the mould; and hence the casting would itself be broken or injuriously strained.

It is amusing now to recall the delight which pervaded my youthful mind when this weighty opinion was pronounced—born, as it was, of a lifetime of acceptance of the orthodox sand foundry practice as it had been employed for hundreds of years. This delight was due to the fact that I had already found a simple expedient which overcame the above-mentioned difficulty.

The "simple expedient" was so to control the time of filling and opening the mould as to allow the casting to remain in the metal die only until it had set hard enough to keep its shape and not long enough to contract to any appreciable extent: an obvious expedient when one considers that shrinkage is proportional to reduction of temperature and that a casting holds its shape while still very hot.

Of course, this practice is now universal where castings in metal moulds are made of high shrinkage metals, and all strong commercial metals I know of are high shrinkage metals. However, giving credit where credit is due, subsequent experience has taught me great respect for the shrinkage factor which retarded progress for a long time because even though the anticipated injury due to linear contraction could be avoided, the contraction in volume of the metal was quite

another matter. In fact, this problem of feeding the internal shrinkage is and always has been a real problem, no matter what form of mould is used. In the present state of the foundry art it is no rare experience to find large shrink holes, especially in castings the design of which calls for both heavy and light sections in the same piece.

Perhaps in a way the use of metal insets or "chills" in sand moulds might have been taken as evidence that the direction of future progress toward consistently sound castings would be along the lines of metal moulds and of some of the accurately controlled means of filling them. At least the use of "chills" indicated the importance of hastening the cooling rate in one locality in the mould over that in another locality, but the full significance of this information has not yet been generally appreciated.

Furthermore, the expedient so generally resorted to of employing heavy risers to provide reservoirs of molten metal to feed the shrinkage locally might have been viewed as more or less prophetic of the future direction of progress as shall later herein appear, since, instead of hastening freezing as in the case of a "chill" before the gate should freeze, it provides a hot liquid supply where most needed, and the stream often continues to feed long after communication with the gate has frozen up.

Another tendency in the sand foundry art may be viewed as pointing toward counter gravity or pressure versus gravity casting, since it has long been known that down pouring or cascading of molten metal directly into the casting cavity is questionable practice, tending as it does to trap air and allow dirt, dross, or slag to enter the cavity. Hence, so-called "hooked" gates or bottom pour gates are quite generally resorted to, so that the injurious effects of down pouring can be minimized and so that clean, hot metal can be allowed to enter the bottom of the casting cavity and rise against gravity under a better controlled "head" than would be possible if poured directly into the casting cavity.

I shall give five other preliminary points drawn from general sand foundry experience and then settle down to the consideration of the new technique.

First. The obvious importance of a nice control of the temperature of the metal to be cast in any given shape and the relative crudeness of the conventional means of effecting this control; and

Second. The importance of minimizing those injuries from exposure of molten metal to the air, other than the temperature variations resulting therefrom.

Third. The tendency to large grain and weak structure when metal solidifies slowly as in a refractory mould.

Fourth. Injurious effect of burned-in sand and grit on finishing tools.

Fifth. The high ultimate cost of sand castings due to necessary machine finishing and the defects disclosed thereby.

My objective has been to take full advantage of all that has been learned by the practice of this ancient art and then so to regulate, control and improve the technique that all of the injurious practices are avoided and that scientifically controlled means shall progressively convert the rule-of-thumb "art" into a precise science.

The trend away from castings and towards forgings and welded structural shapes which has been noted in late years is largely due to the fact that designers and engineers must have uniform reliability, known safety factors and mass production low prices. To restore the waning prestige of the casting is not a simple task, but I am in the process of achieving it through the mastery of the essential and controlling factors which dominate the problem.

This main objective, upon the successful achievement of which so much of the future of the casting industry depends, may then be broken down into a number of scientific and/or commercial subsidiary objectives.

First—We must understand the scientific causes underlying the imperfections and limitations of the conventional methods employed in making castings.

Second—We must invent, design and develop on a full size laboratory or commercial scale the correctives, improvements and new departures necessary in order to insure consistently superior products, without undue human risk or drudgery and with maximum efficiency and lowest cost.

Third—We must select the points of departure and the initial extent of the field most urgently in need of such understanding and improvement in technique and offering, therefore, the most promising prospects of commercial application.

Intensely interesting collateral problems may have tempted me to depart from the chosen shortest route to commercial practicability. Shoals have been encountered, but so far no reefs have wrecked my efforts; and now at last the snug harbor of commercial success seems clearly visible on the horizon.

In maintaining a proper perspective in this discussion it will be necessary to desist from extending the thesis to include a whole range of collateral investigations without which success could not have been attained; such, for example, as

"The behavior of various refractory materials under the combined influence of temperatures above 3000 degrees F., the corrosion of certain ferrous alloys and of internal pressures up to 100 lbs. per square inch"—

or—"The significance of optical and thermocouple pyrometry in controlling modern foundry temperatures"—

or—"The relative heat conductivities of selected die materials measured in terms of their total capacity to absorb heat from molten metal in contact with them during brief intervals of time"—

or—"The relative importance of precisely controlled pressure versus precisely controlled temperature on molten metal during the interval of setting."

MELTING, SUPERHEATING AND TRANSFERRING METAL.

There is no time for a discussion of the annual consumption of castings of the various metals used in industry, but beyond a doubt grey iron leads in the universality of its use. It is cheap and has many properties to recommend it—a few properties which limit its usefulness. To avoid confusion, therefore, this paper will be based on the assumption that the entire technique as described is with reference to handling—let us say—a standard "2X foundry" pig iron with or without additions of steel scrap and/or special alloys.

Anyone familiar with the properties of the bronzes and brasses will observe the entire feasibility of their substitution

for grey iron. A few differences—such as different coefficients of heat conductivity and greater danger of distillation of volatile metals (such as zinc) which the non-ferrous alloys may contain—have to be taken into account in the regulation of temperatures, in melting methods and in sundry time factors, but the principles remain unchanged and some essentials of apparatus design apply to virtually any metal to be used, so long as the temperature ranges are under 3000 degrees F.

So far, although we have made white iron and semi-steel castings, the high temperature necessary for the desired fluidity of low carbon steels approaches so closely to the critical safety limits of the die and furnace materials employed that development of the steel technique has been deferred until after the grey iron is in successful large-scale production. In the interest of brevity I will refrain from discussing at this time our interesting experience with white iron containing carbon under 2 per cent. and silicon well under 1 per cent. Our old specially designed electric furnaces could melt steel and maintain it at desired temperatures, but since it would be harder on the dies than grey iron and since the physical properties of the latter, as cast by our process, so closely approach those of steel, even without the use of alloys, it has been deemed wise for the initial period of research to concentrate on grey iron. I have no doubts, however, as to the ultimate feasibility of developing a profitable technique for pressure casting malleable iron and steel.

Of course, any convenient method of melting may be used provided that it can be employed to melt batches containing the desired quantities and that the rate of melting can be synchronized with the desired hourly output needed to produce the maximum weight and number of castings of which the process is capable.

Naturally the way such a supply could be sustained, if melting were done in the cupola type of melter, would be to have a battery of cupolas charged at "staggered" intervals. Even then the question of temperature adequacy and uniformity would arise and probably the reported Ford practice of storing and superheating metal in an "air furnace" type of forehearth would also be needed.

The electric furnace has the needed batch melting characteristics and can readily provide the desired superheat, and no doubt other means are available. We prefer, however, to use a horizontal rotary oil fired melter which we have designed and built with a special view to our requirements. With it we experience no difficulty in balancing the supply of properly superheated metal with our requirements. Like the electric furnace, this type of melter is well adapted for adding predetermined percentages of steel scrap so as to cut the total carbon content, and of course lends itself admirably to producing consecutive batches of special alloys as, for example, by additions of silicon, nickel, chromium, molybdenum, etc.

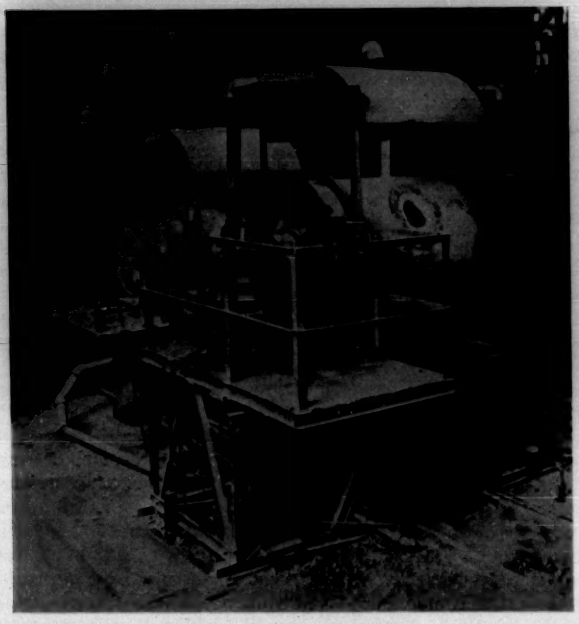
The reasons for superheating are very significant both in the interest of superior physical properties and in the interest of success with subsequent operations under the process. Assuming that an average mix melts at say 2250 degrees F., it is well known that raising the temperature of the molten bath 500 degrees up to 2750 degrees brings the carbon into solution with a resultant fine grained structure. This structure is further improved when, in our process, the metal is subsequently poured hot and cooled and solidified quickly. Many claim that 2950 degrees to 3000 degrees F. is necessary for this effect, but we do not find it so under our operating conditions.

The control of the air content of the flame is important since one of our objectives is the reduction of the carbon from 4 per cent. in the pig to 3.2 per cent. in the iron to be cast and often this is accomplished without the use of scrap steel. The average analysis of our preferred standard mixture is total carbon, 3.2 per cent., silicon, 2.25 per cent., sulphur, .031 per cent., phosphorus, .56 per cent., manganese, .56 per cent. It is generally necessary to add ferro silicon to keep to this analysis. Such an analysis should yield a tensile strength of about 28,500 pounds per square inch for sand castings and 42,500 pounds for die castings.

The efficiency of our melter has been greatly increased by the experimental development of a chrome and magnesite lining mixture, the life of which is not seriously impaired when a layer of insulation between the shell and the lining is employed.

The type of preheater shown in Fig. 1 for the low pressure air requires improvement in the interest of greatest speed of melting and greatest fuel economy—but our present practice is quite in range with and often below average costs and is very convenient.

FIG. 1.

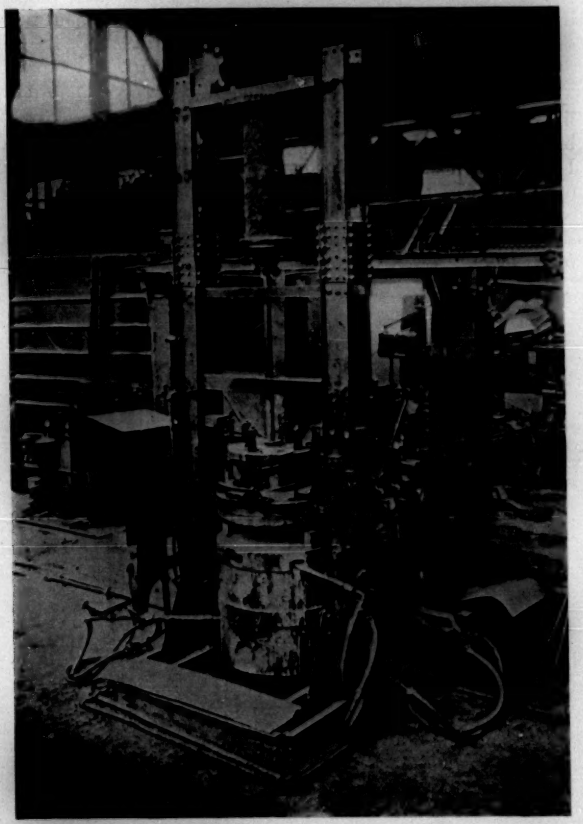


It has been gratifying to note recently in scientific journals that our melting practice is in line with the claimed improvement in the strength of grey iron, due to its being in direct contact with the products of combustion of a controlled flame.

As to the technique of transferring the superheated metal from the melter to the casting unit, little need be said other

than that an open shallow ladle is used and time given for slag and impurities to rise to the top. This is made easy by the high temperature at which metal is withdrawn from the melter. In practice, a slag bridge forms almost instantly

FIG. 2.

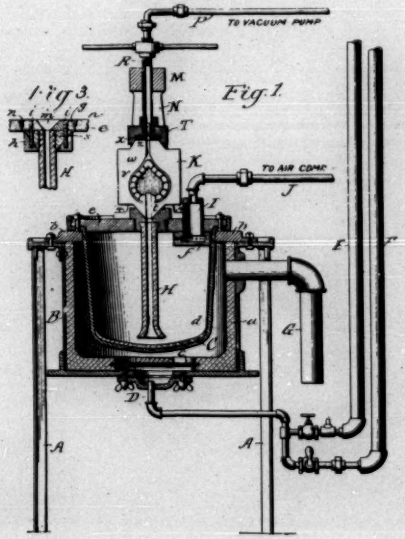


and bubbles or arches up from the surface. This protects the bath from oxidation or too rapid loss of heat and the fluidity of the hot metal encourages the escape of gases and impurities. The vibration of the electrically-operated car carrying the charge a few yards to the caster (see Fig. 2) further helps to purify the charge—which is then poured directly into the casting unit at a temperature of about 2650 degrees F.

LIFTING MOLTEN METAL AGAINST GRAVITY.

Before proceeding to discuss the most modern technique of lifting molten high-melting-point metals against gravity, a brief review of the series of patents which my associates and I have taken out since 1906 will facilitate an understanding of the precise nature of difficulties involved in order so to control all of the vital variables at the same time that consistently good results on a commercial scale may properly be realized.

FIG. 3.

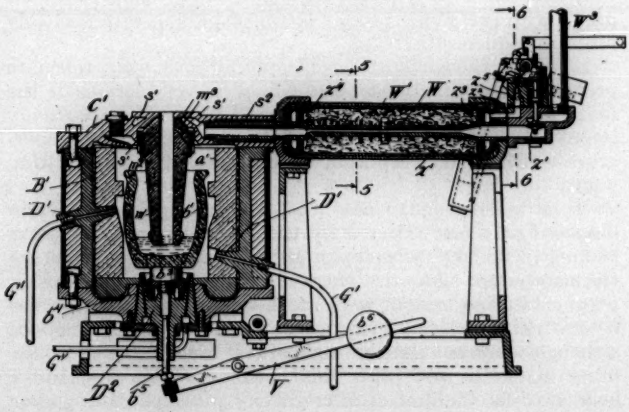


U. S. Patent No. 1,029,565, S. P. Wetherill and J. P. Wetherill, Jr. Application filed September 8, 1906, allowed June 11, 1912. See Fig. 3.

This design exemplifies an early attempt to develop a cast iron pot strong enough to resist the expansive pressure of the compressed air employed to force the metal upward into the die and at the same time capable of withstanding any heat which, in order to reach the contained metal, would have to pass through the iron walls of the pot. This type of furnace was used for many years in successful commercial production with alloys melting in the vicinity of 1000 degrees F. or under. Attempts to cast yellow brass were not successful as at the temperatures of molten brass the walls of the pot would not stand the necessary pressure. A series of aluminum and zinc alloys were developed which were successfully handled in this type.

U. S. Patent No. 1,150,318, S. P. Wetherill, Jr. Application filed January 27, 1908, allowed August 17, 1915. See Fig. 4.

FIG. 4.



As a result of experience in the use of apparatus previously discussed, it was decided to carry the molten metal in a crucible which, in turn, was enclosed within a refractory-lined pressure-type furnace; all so arranged that the burner employed to heat the crucible could be kept in operation and the products of combustion allowed to escape during the intervals when the die was not actually in contact with the furnace. Of course, during the operation of filling the die, the fuel lines were closed and the exhaust port stopped by the die itself. In this design the pneumatic pressure filled the entire combustion space as well as exerting pressure on the surface of the molten metal contained in the crucible. This feature balanced the internal and external pressure on the crucible proper and hence relieved the crucible of the necessity of withstanding any strains other than the weight of the contained metal itself. This apparatus was constructed and actually operated with the resulting production of quite a number of brass and bronze castings. Of course, there were a few points which would have to be changed to bring it into accord with our latest experience, but the principal reasons for its abandonment were:

1. The great danger of an explosion in the event of insufficient scavenging of fuel oil or gas, since high pressure air mixed with fuel would cause a terrific explosion with probably fatal consequences.

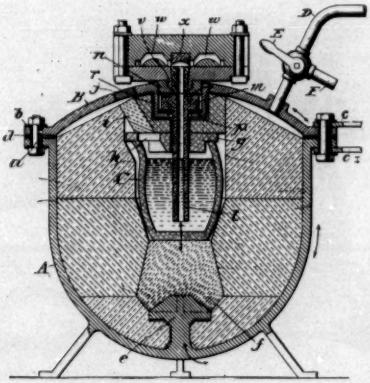
2. Even though considerable precautions were taken to preheat the air, the heat losses would be very serious as the frequency of operation increased, and it would be virtually impossible to maintain the top of the dip nozzle at a temperature which would keep iron, for example, above its melting point.

It is interesting to note that the new principle herein disclosed was first rejected by the German patent office as lacking in novelty, whereupon an appeal was taken and the German patent allowed. None of the sample castings which I am exhibiting tonight were made with this apparatus, and it was not employed in consistent commercial production, although we have a dated sample of test bar castings of yellow brass made in 1908 with this machine. This test bar I believe to be the first counter-gravity pressure casting ever made of yellow brass.

U. S. Patent No. 1,126,079, A. L. J. Queneau. Application filed June 19, 1909, allowed January 26, 1915. See Fig. 5.

In order to overcome the limitations and the dangers of the previous types, the services of Mr. Queneau, an electro-metallurgical engineer, were retained for the purpose of developing means for transmitting heat to the metal in a refractory container without having either to pass the heat as such through the pressure-resisting walls or to pass any flues or fuel lines through them. In this design it will be

FIG. 5.

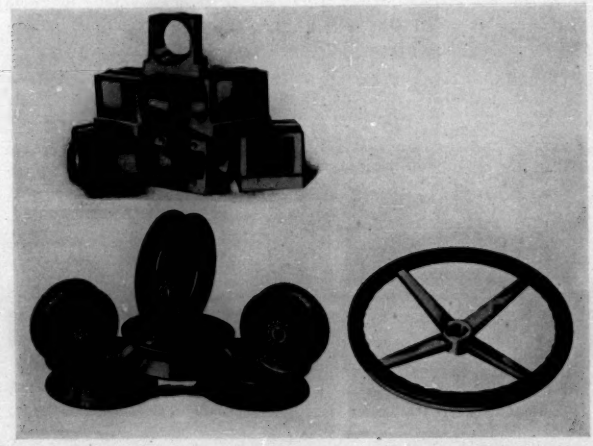


seen that the electric current was led to a metallic cover which was insulated from the metallic enclosure of the base, but that by grounding one terminal to the base a high amperage and low voltage current could be passed through the whole apparatus. In one design the current was conducted from the lid down a non-metallic electrode, preferably composed of carbon similar to that used in the modern type of electric-arc furnace, the upper end of the carbon being grounded to the lid and the lower end being immersed in the molten metal. A high-conductivity graphite crucible was

employed which in turn was placed upon a graphitic base which was capable of transmitting the current but which, because of its special composition, offered great resistance to the passage of the current; hence generated heat and acted much as a stove plate in maintaining the crucible at the desired temperature.

Nearly all of the brass and bronze samples exhibited here (see Fig. 5A) were made with this type of furnace, and I have

FIG. 5a.



been told that Dr. Steinmetz of General Electric fame commented very favorably upon the relative advance of this furnace in view of the then state of the electric furnace art. This furnace could be regulated to a nicety by the control of the supply of current, and successfully made castings of monel metal, phosphor bronze, and manganese bronze. Insofar as the furnace proper was concerned, even grey iron was successfully handled, although the die operating mechanism was so slow that the grey iron casting made therein cracked to pieces before the dies could be opened.

The disadvantages of the furnace were that it required a tremendous volume of compressed air and that the life of the communicating dip nozzle was necessarily short since long sprues or runners invariably froze in the space between the molten bath and the entrance of the casting proper. Other commercial difficulties were that the transformer equipment was extremely expensive and that the induction losses were very high. I believe, however, that this machine would long ago have been in commercial operation with perhaps slight modification had it not been for certain untoward commercial events which in 1911 put a stop to our further technical progress.

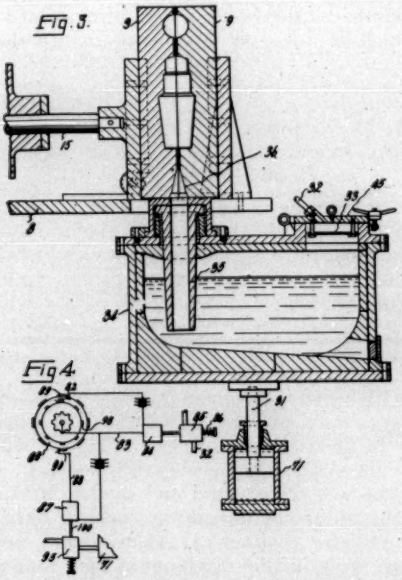
U. S. Patent No. 1,746,360. U. S. Patent No. 1,747,728.
A. W. Morris and S. P. Wetherill, Jr. Application filed December 1928 and January 1929, both allowed in February, 1930.

While, to the superficial, both of these patents would appear to be confined largely to mechanical details of the casting machine, they introduce an entirely novel process in that in this type of pressure pot no heat is applied to a refractory-lined pressure ladle other than that which remains in it from the metal with which it is charged (see Fig. 6 illustrating these patents and No. 1,913,945). In this way a well insulated and strong cast-steel pot can be used. The rapidity with which the metal is charged and discharged is relied upon to make up for the radiation and cumulatively to build up a high enough operating temperature within the pot to prevent the skulling or freezing of the metal.

This type was constructed and used to make large grey iron castings with some measure of success. The samples of grey iron radiator castings, 4″ valve stems, and 4″ valve bodies were made in this machine; in fact, four valve stems weighing 35 pounds each were cast at a time, thus discharging approximately 160 pounds of metal per operation, including gates. This principle, however, required rapid and continuous operation with large size castings in order that the supply of new heat units from the hot metal should be abundantly able to make up for the radiation. This device is not considered practical for small castings or where there is any serious danger of interference with consecutive operation.

We found in practice that the supply of molten metal was frequently interfered with, and the delays resulting from this gave time for the loss of too much heat from the casting unit. If the attempt was made to hold a potful of hot metal this would have time to skull and clog up the casting nozzle or, if the metal was poured off, the pot would get cold and the next charge would be chilled with a similar effect. All this experi-

FIG. 6.



ence was very valuable, however, since it taught us the importance of reducing radiation to a minimum by employing the stored heat in the molten metal to the best possible advantage in keeping up the temperature of the line of communication between the molten bath and the die cavity.

In comparison with the importance of this phase, all of the other problems become mere mechanical and metallurgical

details, since the basic essential to sound castings is the preservation of liquid communication throughout the time interval required to solidify the heaviest section of the casting being formed in the die cavity.

Experience with this so-called "thermos bottle" type of pressure pot explained away the mystery of the difficulties experienced in making small castings with the same equipment which very readily produced large ones. It is now obvious that the thermal units in a small charge are not sufficient to heat up the passageway which could be heated almost to destruction by a sustained stream supplying new heat units faster than the old ones could be dispersed by conduction or radiation. If critically analyzed, however, it will be seen that no adequate means is provided to check heat loss from the top of the dip nozzle, the comment which was made with reference to the electric furnace apparatus being likewise applicable here.

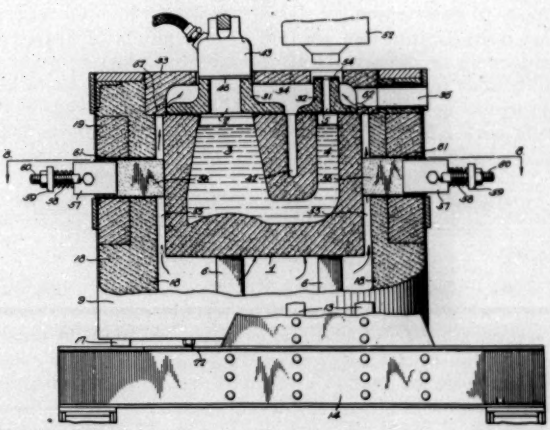
U. S. Patent No. 2,018,586, S. P. Wetherill, Jr., and F. F. Shoemaker. Application filed June 4, 1934, allowed October 22, 1935.

Under this application two new principles are disclosed, both of which involve the use of an airtight refractory crucible closed with an airtight lid and being heated from the outside by any one of a variety of different means. Until recent years no plan to employ a refractory material to withstand a combination of heat and internal expansive pressure would have been deemed even sane, since at the high temperatures required even the best refractories were known to soften and lose their strength. Their well-recognized characteristic of extreme porosity was also a disadvantage. Fortunately, however, the state of the refractory art is advancing rapidly, and we have conducted a long series of destructive tests on all available refractory materials which give any promise of meeting the exact requirements.

In the early stages of our development, we did not dare trust entirely to the unsupported walls of the refractory to resist the bursting strains caused by the pressure necessary to lift the metal from the crucible into the die, and we therefore

provided means (see Fig. 7) of transferring some of the internal expansive pressure through the refractory walls and through snug contact members back to the remote iron structure surrounding the crucible. We found, however, considerable difficulty with the crucible manufacturers in procuring special shapes of uniform strength and density. We also found that circular crucibles were much cheaper and stronger in proportion to their capacity than any irregular size.

FIG. 7.

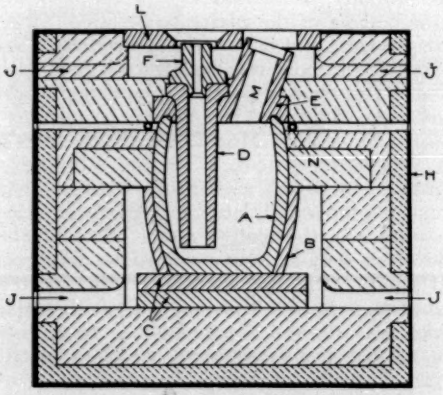


We therefore evolved rapidly om the precise design shown in the patent to a modifica thereof, which still conforms strictly to the claims allo (see Fig. 8). The disadvantage of this type is the nec for crowding into the lid space the required openings: or discharging metal through the dip nozzle and the other fo freely pouring in new charges and for skimming and remo slag, etc. These large openings introduce a problem o rength of the lid which has, however, been satisfac overcome. An expedient is resorted to of having two separate combustion chambers: one whose function is to maintain the metal in the

crucible at the proper temperature, and the other whose function is to prevent or compensate for radiation and conduction of heat away from the pouring and the charging openings.

The experience with this type has been most gratifying; and commercial quantities of castings have been manufactured with this type of equipment. In the light of the experience thus gained we have designed our "1937 model" with a view to a lower cost and longer life and a greater thermal efficiency. Strange as it may seem, however, we

FIG. 8.



much prefer to employ the principles covered by this patent than to resort to the electric furnace; and we are experiencing no serious difficulties due to the properties and limitations of the refractory materials now available, at least so far as the smaller diameter crucibles are concerned.

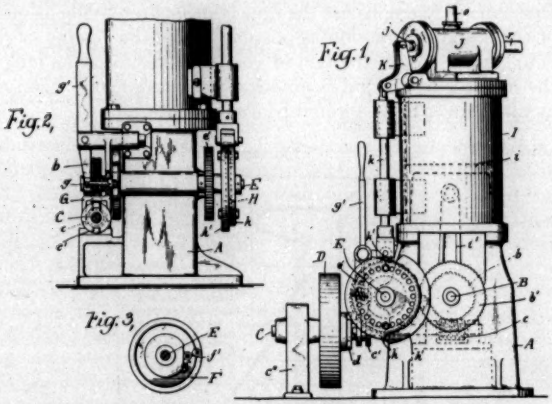
The above summary of alternative furnace types, of necessity, neglects a great number of significant details. It is hoped, however, that it has clarified the essential distinction between the different types and indicated the limitations of the state of the art before the later types of pressure-resisting refractories had been developed. My own conclusion is that

our experience has now definitely emancipated die casting from the earlier limitations and opened the way for the manufacture of die castings of any metal which can be melted by contemporary foundry methods. Until this phase of the work had been put upon a reliable basis, all of the other refinements necessary to commercial die casting of high melting-point metals were at a standstill.

Now that it has been done, however, the experience gained in making die castings of various metals, including even the very low-melting point ones, is not without some bearing on the subject here under consideration. For example, any metal to be properly cast should be lifted as in a slowly rising tide into the bottom of the cavity to be filled. The reasons for this are obvious, and have already been discussed. The means of attaining it, however, are not so obvious, although an examination of this class of patents shows that others as well as ourselves have recognized this need. In fact, as early as July 18, 1911, Mr. A. W. Morris, then serving as my chief draftsman, procured a patent, U. S. No. 1,039,173, allowed September 24, 1912, which was entirely dedicated to a very slow hydraulically-operated building up of pneumatic pressure above the surface of the molten metal to avoid the uncontrolled and often semi-explosive variations when cold air is introduced against the hot surface of the molten metal. Under that same date Mr. Morris and I jointly applied for a patent which was allowed September 24, 1912, bearing the U. S. No. 1,039,234, by means of which a mechanically-operated piston slowly intensifies the pneumatic pressure to the degree necessary to lift the metal into the mould, and thereafter automatically permits the entrance of high pressure to assist in forcing the metal supply into the casting cavity (see Fig. 9). This latter equipment was employed to very great advantage in the production of aluminum castings such as, for example, the F. B. Stern steering wheels (see sample exhibited). It was found that with the use of this apparatus it was no longer necessary to call upon human skill to control the admission of the pressure into the furnace and that more consistent results were obtained when the machine was properly adjusted than were possible by hand. While there have been many adaptations of these principles to suit them

to the various modern types of equipment, they apply with equal force to the present art of die casting high melting-point metals as they did before it was practicable to die cast iron.

FIG. 9.



REMOVING SUPERHEAT FROM AND SOLIDIFYING METAL.

In dealing with iron and the brasses and bronzes, it is necessary to give meticulous attention to the phenomenon of contraction in volume which takes place when liquid metal becomes solid and as the temperature of both liquid and solid metals falls.

Much help in grasping the nature of this problem can be had by reference to the scientific literature on the subject. In the December 1st, 1930, "The Foundry" magazine, there was published a most interesting and helpful chart in connection with an article discussing the engineering properties of grey iron. This chart is reproduced in Fig. 10 and clearly shows that the rate of volumetric contraction or "shrinkage" continues with the falling temperature, whether metal is in a liquid or a solid state. It also shows that at the instant of solidification there is a very marked reduction of volume. It shows additional peculiarities of grey iron which would in

themselves justify an interesting scientific paper, but for the discussion of which we have no time here other than to say that these phenomena indicate that grey iron is much better adapted to the manufacture of sharply-defined die castings than probably any other high shrinkage metal known. The chart serves to emphasize the importance of removing as much of the liquid contraction as possible before the casting cavity is full, since the contraction in volume is very slow so long as the metal is liquid and is practically instantaneous when the metal changes from a liquid to a solid state.

FIG. 10.

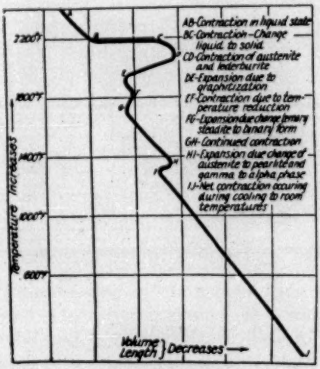


Diagram of expansion and contraction effects in cast iron.

Since one of the essentials of successful die casting of high melting-point metals is the protection of the die from excessive thermal punishment, and another is the most rapid possible solidification and ejection of the casting, it will be apparent that it is essential to avoid filling a cavity with extremely hot metal which will have to lie for an appreciable time interval in the cavity before it solidifies. Therefore, it has been necessary to study the shrinkage phenomena at various temperatures both before and after solidification to provide means for removing a predetermined number of heat

units from the metal in its passage from the molten bath to the casting cavity in the die.

For the metallurgical reasons previously discussed it is desirable that the bath be several hundred degrees above the melting point, and it has been necessary for us to interpose between the die cavity and the molten bath predetermined areas of highly-conducting surfaces in contact with the molten metal, with means for absorbing the required number of heat units and no more.

We have patents pending on what are called "sting remover gates," the characteristics of which are that the heat withdrawn from the metal as it passes the cooling area, while conducted away from the molten metal, is nevertheless stored up in the walls surrounding the molten metal; so that once the casting cavity has been filled with cooled metal, thereafter during the required time interval before the casting is completely solidified, the passageway will remain so hot that a liquid supply will be available to feed the last drop necessary to replace the contraction in volume of the casting proper.

To me, the evolution of this technique appears of tremendous importance in the whole casting art. I believe that, possibly without its being fully understood, this principle has been assisting the makers of low melting-point die castings where their gates have been led through fairly long channels in contact with the metal mould; and I have no doubt that it has also been operating in gravity pouring in metal moulds. By establishing a precise scientific control, however, which permits first a dispersion and subsequently a conservation of heat, we have found it practicable to pour castings of extremely heavy sections, say, for example, 2" or more, through a properly designed gate less than ¼" thick and still completely avoid shrink-holes in the casting.

An interesting example of the progressive freezing of the casting and of the cumulative storage of heat in the passageways is exhibited. The die for a 5" diameter grey iron roller was being filled when a defective gasket blew out, releasing the pressure. Whereupon, all of the metal, which had virtually filled the mould but had not yet frozen, ran back by gravity into the casting pot through the thin gate, the channel through which it had entered, leaving a shell of tapering wall

thickness as a measure of the length of time that the molten metal had been in contact with the cooling surface of the die. This exhibit also shows that we have successfully overcome any tendency to spurt or spray the metal into the cavity, which would, of course, have been impossible without a scientific control of the building up of the pressure in the pot.

A very interesting phenomenon has been observed in studying the cross-sections of castings made by this process. There is visible evidence that when the casting is first formed, a skin of metal to a depth of approximately $\frac{1}{8}''$ is quickly formed. Subsequently there is a lull in the rate of solidification, and then another layer is formed exactly paralleling the face of the first, and so on in to the center of the casting. This has led us to study the evidence available that the heat bombardment from the hotter part of the casting to its own frozen surface or from the surface of the casting to the die, proceeds, as it were, in successive bursts with a definite time interval between the bursts, during which the temperature differentials become favorable for a new burst. We incline to the belief that the discharge of the latent heat of fusion builds up an instantaneous high temperature on the wall adjoining the molten metal, and that not until this heat has been dissipated is the temperature differential favorable to another burst or wave of heat.

The above phenomenon should not, however, be interpreted as an indication of any weakness in the casting; but rather, it aids in the explanation of the increased density of this type of casting in comparison with the slowly solidified sand casting. An exhibit is available of a polished cross-section of a casting showing this characteristic. No physical cleavages have been noticed when fractures of castings of this type have been made, and the visible evidence of this phenomenon is entirely eliminated by annealing.

TIMED REMOVAL OF HOT CASTINGS.

The quick removal of castings from the die is important primarily in order to speed up operation, to avoid overheating the die, and to avoid injury to the casting which would result from appreciable contraction of the casting against the rigid structure of the mould. In the case of cast iron, however,

the accurately-timed removal takes on additional significance due to the fact that unless the casting is removed from the cavity before any surface of it has cooled below 1800 degrees F., such a surface would be chilled, and the depth to which the chill would penetrate would be proportioned to the length of time during which the casting had been permitted to be cooled by contact with the die. Where chilling is not desired and a machinable surface is wanted, it will be evident that there is no time to lose in removing the casting from the die. With very thin sections this factor becomes of critical importance, and definitely limits the feasibility of making machinable castings by this process, unless the castings are to be subsequently annealed.

Very often, however, it is desirable that some surface of the casting, as, for example, the teeth of a gear, should be chilled to a sufficient depth to insure long-wearing qualities, and the remainder of the casting should be soft to permit of subsequent machining in cases where the die cast finish does not bring the part to its final dimensions. In the case of very heavy castings it is often necessary to keep the die closed and the pressure on the liquid metal supply long after the cavity has been filled with molten metal, in order to permit the solidification of the casting and make sure that no molten metal "bleeds" from its hottest section. We have found in these cases, however, that the heavy section of the casting has a sufficient amount of heat stored up so that, even after a contact of over one minute with the die surface, this stored heat self-anneals the entire casting, and the surface which would otherwise have been too hard to machine is soft enough to machine. Embarrassment comes when such heavy sections are combined in the same casting with light sections, in which event a chill becomes necessary whether it is desired or not; and if not desired, can be removed only by annealing.

We have found, however, that the length of time during which a casting may safely be left in contact with the mould without the danger of chill can be increased by reducing the wall thickness of the die in those zones where chilling is to be avoided. The consequence of this is that such superheat as remains in the metal plus the latent heat of fusion given off when the metal solidifies quickly, raises the temperature of

the die walls near the critical chilling temperature. In such cases, of course, the mass of the die wall must be properly calculated with relation to the number of heat units it is intended to absorb in the process of arriving at the proper temperature.

DESIGN, CONSTRUCTION AND REPLACEMENT OF DIES.

The designing of an operable die for any given part requires considerable familiarity with the technique of the process, and in doubtful cases must still be regarded as an experiment. There is no doubt, however, that design requirements are much more limiting in metal mould casting than they are in sand-mould casting. Were it not for the fact that we have demonstrated it to be perfectly feasible to combine sand cores with metal moulds, the field for metal mould castings would be greatly restricted.

Among the exhibits there is a radiator section which has been cut away to show that while the outside is cast against a metal die, the inside surrounds a sand core. The close grain induced by the process insures a steam and moisture tight metal very desirable for this class of work. Another example of the use of the sand core is that of the four-inch valve body also exhibited. Metal cores can, of course, be used where the draft is favorable.

When it comes to selecting parts suitable for manufacture by the process, the quantity factor and the cost of procuring similar parts by competitive methods loom very large in making the choice, because if the money incentive is sufficient and the quantities are large enough, a considerable expenditure of engineering thought on the proper design of the die is justified, as is also a considerable outlay for a fairly complex and expensive die. The experienced designer dreads the necessity for dealing with very small parts, both for the metallurgical reasons cited and because it is necessary to go through the same mechanical motions and employ the same amount of labor and furnace time in making a small part as in making a large one.

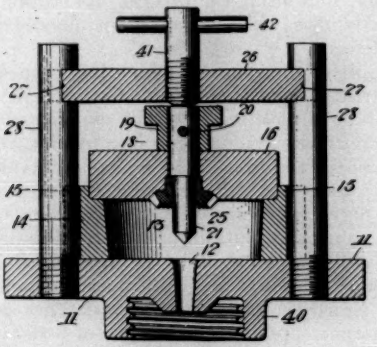
Of course, both of these difficulties can be largely offset by making a large number of impressions in a single die. This adds materially to the die cost, but vastly increases the hourly

output, and if the quantities justify it, makes possible very low prices. The most serious mistake that could be made, however, would be to assume that virtually any casting wanted would be commercially applicable to the process, since such an assumption would require the provision of a very large staff of highly trained die designers and would involve too large a proportion of time and money in the design and manufacture of dies and too small a proportion of time and money in putting out a profitable finished product. We therefore lean to a deliberate policy of limiting the market to parts that lend themselves well to the process and command a price considerably above the competitive cost of sand castings. This policy should certainly obtain until any manufacturers that were using the process had accumulated a very large stock of dies which were in sustained production for large quantities.

As a result of the progress which has been made to date in the centrifugal casting of grey iron pipe in water-cooled steel moulds, and as a result of the experience which is accumulating in the hand pouring of iron moulds, there has been great progress in the iron alloys which are available for the making of dies. Nevertheless, the punishment to which these dies necessarily are subjected is severe, and I have adopted certain expedients intended to minimize the injury resulting from local overheating in the die; even though no extraordinary metallurgical virtue might attach to the material from which the die is constructed. For example, it is well known that exposing one surface of a heavy section to high temperature, while the other surface is relatively cool, is disastrous because of the strains set up due to the relatively greater expansion on the hot surface. I have, therefore, developed a technique of using thin sections which are anchored positively in position but which are free to expand instantly upon contact with the hot metal and free to contract as soon as the hot metal is no longer in contact with them. This policy has greatly increased the life and cheapened the construction of the dies to which it is applicable. It also makes possible the practice referred to in previous chapters relating to the mass of the die wall being properly proportioned to the amount of heat it is desired to carry away, since very light plates and forms can be inserted for this purpose.

Perhaps, however, the most significant development looking toward the cheap construction and replacement of dies has been the technique we are developing of die casting our own dies or the critical segments of dies which are subsequently inserted in the die operating housings or mechanisms, whether for single or multiple impressions. As long ago as October 12, 1909, our Mr. Queneau applied for a patent on method and apparatus for die casting those die sections which would be cheap to die cast and extremely expensive to machine (U. S. Patent No. 1,043,867, allowed November 12, 1912). See Fig. 11. A sample of such a die cast beveled

FIG. 11.



gear die is herewith exhibited, and the patent describes in detail how it is made. Briefly, an oversized gear is made with a double allowance for subsequent shrinkage. This gear is anchored into place in a convenient form, and the metal cast around it, resulting in a very accurate negative which might cost at most a few dollars in comparison with perhaps thousands of dollars for accurately engraving any such part if, in fact, it could be engraved at all.

The use of this principle means that even though considerable outlay is made for the master die, it is very cheap to die cast dozens—or even hundreds, if they were needed—of

impressions which are cheaply anchored into a convenient housing. If now the life of the die should prove very short, it is only necessary to scrap the old insert and employ a new one in its place. There is exhibited herewith a sample of such a die cast negative for the production of flatirons. See Fig. 12.

FIG. 12.

While the patent of Mr. Queneau was taken out a long time ago with reference to the use of non-ferrous metals, our recent technique proves its great importance in the field of die casting grey iron, as the most valid criticism of my process is that the life of the die is short and that machined steel dies are expensive. The development of the apparatus which has made it possible to make iron die castings promises the solution of the problem of bringing the cost of the dies and their replacements within reasonable bounds.

We fully recognize, however, that we have by no means solved the problem of finding the best iron alloy for our dies or castings. While concentrating chiefly on process technique and apparatus we are also endeavoring to keep abreast of the latest metallurgical developments so essential to our ultimate success.

THE FINISHED PRODUCT.

Any exhaustive discussion of the characteristics of grey iron cast by this process would involve entering into the scientific consequences of the entire procedure to a greater degree than time and space will permit here. Nevertheless, we must, at least, take time for a hasty review of the consequences of the various steps above described in terms of the qualities of the product. The question has frequently been asked as to why I take so much trouble to "push hot metal uphill when it is so easy just to let it run down." The question is both fair and rational, but, of course, it is born of an almost total ignorance of the demonstrated value of the die casting or pressure casting art in the low melting-point non-ferrous field. It is hard for those of us who have been deeply immersed in overcoming the problems, to see ourselves as others see us and take seriously such a question; but there is value in the effort to take account of stock and try to define the advantages which those skilled in the art take so wholly for granted.

In the first place, whatever value, for the remote future, abstract research may have, it is, I believe, thoroughly orthodox to assume that an equally good product at a lower cost or a better product at the same cost justifies a struggle to attain them. If it can now be shown that a better product at a lower cost is destined to result, then surely the research and development work necessary for this attainment is doubly worth-while.

To appraise intelligently the advantages of counter-gravity pressure die cast iron, the first step should be to realize the reasons which underlie the immense extension of a low melting-point die casting business during the past two decades. Essentially, it has been found that by pressing metal into the die cavity after the exercise of great care in the production of accurate dies, accurate products result with a consequent elimination of the need for machining away surplus stock which is required when an accurate part is to be made from a rough sand casting.

Collaterally, however, to this obvious advantage are numerous advantages not so obvious but perhaps even more important. It is generally well known that the surface of a

casting, which always solidifies first, is the densest and the strongest part of the casting, and that beneath a casting skin the tendency is toward less strength, larger grains, and porosity. For this excellent reason a casting which is initially formed exactly to the desired shape preserves unbroken the strongest part of the casting in the skin. The overcoming of the disadvantage, then, of machining away the strongest part of your sand casting, is a real gain and is not made less significant by the fact that your die casting properly made is more homogeneous throughout its entire thickness.

A great service would be rendered if statistics could be compiled showing the number of tons—or should I say millions of tons?—of grey iron castings which are made annually in this country, only to be discarded to the scrap heap when the machine tool, cutting through the skin, opens up an internal defect, the presence of which was not known until after considerable machine labor had been expended. If costs were always figured to include the cost of these rejections and their incidental losses, this alone would justify the painstaking efforts to substitute means of producing uniformly sound and solid castings. I believe this statement would apply even were there no elimination of machine work.

Again, there are many industries using castings which have to stand considerable hydraulic pressure; as, for example, in radiator and steam valves and similar parts requiring what the trade speaks of as "pressure-tight iron." A glance at the comparison of the conventional sand casting of the same wall thicknesses with the product under consideration leaves no room for doubt as to the superiority of the latter in this field.

The chemical nature of grey iron introduces what at one time was considered an insurmountable obstacle, and what has now become under our latest technique one of the greatest advantages of the process in the grey iron field. I refer to the tendency of grey iron to chill and become too hard to machine, and even glassy brittle if allowed to cool in contact with the metal mould below the critical chilling temperature. The greatly-increased density which we get from the rapid cooling of the iron and its effect upon the size of the graphite grains more than offsets the extra expense of annealing to soften the iron, in case some of the surfaces of the casting require

subsequent machine finishing. Modern methods of "box" annealing have been developed to a point where the cost is trivial and the formation of a scale or oxide on the outside of the casting can be entirely prevented. Our most advanced technique, however, is rapidly attaining the point where the casting can leave the die in a condition requiring no further machining except the grinding off of the gate and cleaning off of minute fins which result from the metal running into the air vents (see Fig. 13). This is developing a whole new field where a hard surface is desired but where the center of the casting must remain strong and tough. There are those who believe that this advantage alone would open up large enough

FIG. 13.

fields to have fully justified the research which has been conducted.

One is inclined to agree with this view when it is realized that in addition to an average increase in density of about 10 per cent. over a machined sand casting, these die castings can be made accurate to within two or three thousandths of an inch per inch of dimension, and that the depth of hardness can be accurately controlled so that, in the vernacular of the foundry, the iron may be "chilled" or "white" to any desired depth while the hub or center remains black, soft and machinable (see Fig. 14).

In the matter of costs, the great savings which it is possible to effect by the use of this process cannot now even be guessed at, since each piece requires study on its own merits and with relation to the competitive cost of producing a similar piece

by the old method. In a general way, however, it is safe to say that the output per man hour and per square foot of floor space by this process would stagger the credulity of the mathematician who multiplies the hourly rate of which a machine is capable—even when hand-operated—by the number of pounds in each piece produced, and the number of hours in a day. Let us, for example, consider that two workmen can operate an inexpensive die operating mechanism at

FIG. 14.

the rate of from 20 to 30 operations per hour, and consider that the minimum desirable weight per operation would be, say, 20 pounds. It will be seen at once that these two men would be turning out 400 pounds of product per hour. Now take into account the fact that the selfsame equipment is capable of making much larger castings at almost the same rate of speed, and it will be seen that the same two men could easily turn out 1,000 pounds or more per hour with hand-operated "single head" machines.

If now we instruct a machine designer to mechanize the process and introduce the multiple head turntable with high speed cooling and more fully automatic equipment, it becomes apparent that the only essential to ridiculously low costs of production is that the parts shall be required in sufficiently large quantities to justify the making and setting up of the necessary dies and die-operating equipment.

It is confidently believed that the process lends itself most happily to the modern American trend toward the standardization of design for the mass production of low-priced products. Fortunately, however, long before the time arrives for the substantial capital outlays which such mass production program implies, there appear to be quite a number of parts which cost so much to make by the competitive methods that their sales price bears no appreciable relationship to their cost by this process. This means that there are many fields wherein the margin of profit is so large that the hourly profit on each casting unit should contribute enough to justify a high die cost and a high setting up cost, and still show a very handsome daily or weekly profit from the sustained operation of the machine.

The limiting factor in this respect is the rapidity with which an accurate understanding of the advantages of the process can be extended to the engineering and designing professions so that they may take the full advantage of the process for their own particular requirements. Although not now permitted by my patent attorneys to make an announcement of present developments for still further improving the accuracy and finish of the castings through the use of higher pressures, I hope soon to be able to do so.

THE FEASIBILITY OF AUTOMATIC OPERATION IN MASS PRODUCTION.

I am greatly embarrassed to have to acknowledge that I have been guilty of a breach of the very sound German precept, which is "Do the first thing first." Having before the War completely convinced myself that I had demonstrated the feasibility of the fundamental principles of die casting the high melting-point metals, I presumed that my experience with the non-ferrous metals had been sufficient to justify the construction of an automatic machine which

was to be fed with any of the high melting-point metals in general but with grey iron in particular.

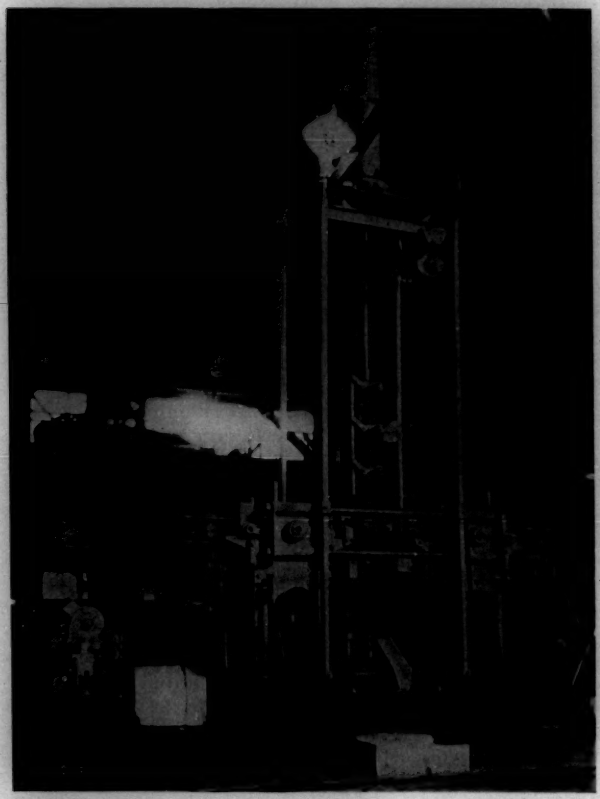
This optimistic assumption did not prove entirely justified, for reasons which are all revealed in the foregoing chapters to him who has the eyes to see. On the grounds of this optimism the services of my former chief designer, Mr. A. W. Morris, were retained, and a pneumatically-operated automatic casting machine known as "Cast-o-Matic" was designed, built and operated with a wide variety of dies. To Mr. Morris's credit be it said that in all of its automatically controlled operations the machine functioned to perfection; that every step not only can be, but was, accurately timed by an attachment known as the "Control-o-Matic," equipped with a series of cams which opened and closed the compressed air valves which, in turn, raised the pressure pot against the bottom of the mould, held it there during a timed interval, while the molten metal was lifted against gravity into the mould, withdrew it at a timed interval, opened the mould, ejected the casting, and laid it in the position of an imaginary conveyor belt, even picked up a sand core and held the same in accurate relation to the sides of the mould while they closed around it, and again repeated the cycle.

Moving pictures were taken of the machine thus operating, and prominent men in the foundry industry witnessed demonstrations in the old plant of the Cresson-Morris Manufacturing Company in Philadelphia and in the plant of the Pratt & Cady Manufacturing Company in Hartford, Conn.

This thirty-ton machine (see Fig. 15) is modestly kept in hiding awaiting the day when a pressure-tight ladle of the type recently developed shall be fitted to it and when it shall be equipped with a die of our most modern design, and when orders shall be received for a large enough quantity of some casting or group of castings weighing from 100 to 200 pounds to justify putting it into 24 hours' day in and day out sustained operation.

This particular automatic machine is designed for large parts such, for example, as a gas engine cylinder block, but its use is not to be expected otherwise than in conjunction with a vast modern mass production foundry which will be

FIG. 15.



capable of supplying it with a 24-hour stream of metal at the proper temperature and which will be equipped with the necessary cooling and conveying equipment to handle a vast output.

Truly we did the second thing first, since the more immediate opportunities for the process deal with smaller pieces, and the advantages of the process are such that even though the fully automatic machine is not used the saving is attractive with simply a semi-automatic device of the general character hereinbefore described.

Since the primary function of the process is the manufacture from hot molten metal of especially shaped blocks of iron ice, the fundamental method of the process is controlled refrigeration. Therefore, the speed of output from any one die will be controlled by the rate at which the heat which is transferred to that die from the molten metal can be dissipated without accumulating. There must be a balance between the inflow and the outflow of the heat. The water cooling of dies has been demonstrated to be feasible in certain selected fields. The expedient of providing as many as 12 dies per casting station has been resorted to in the hand-pouring of metal moulds in order to give time for the gradual dissipation of the heat; and we ourselves have patents (U. S. Patent No. 1,856,352, A. W. Morris and S. P. Wetherill, applied for December 1, 1929, allowed May 3, 1932; U. S. Patent No. 1,913,945, A. W. Morris and S. P. Wetherill, applied for May 6, 1931, allowed June 13, 1933) for bringing such a series of dies to a pressure casting equipment for lifting the metal into the dies against gravity.

We see no reason why such a turntable mechanism could not be operated at very high speed, even though the different moulds mounted on the turntable need not be for the manufacture of identical parts; provided always that they are of sufficiently uniform weight to permit of a similar timing of their heat radiation.

Mortifying as it is to have to realize that we designed and built an automatic machine which we could not supply with molten metal, the picture is not entirely black, since the attempt to maintain this machine in sustained production demonstrated beyond peradventure the need for different methods of melting and getting away from dependence upon the use of the conventional cupola. We now feel that having been compelled to deal separately with each of the various elements which must be in synchronized operation, we have

laid the foundation of experience and data upon which to rear the structure of future adaptations of the process for a wide range of parts and a wide variety of production problems.

The experience leads to the conclusion that it is only a matter of time until the old will give way to the new, at least insofar as standardized mass production is concerned.

CONCLUSION.

I hope that our extensive research and development have demonstrated that we have mastered the controlling factors essential to the production of uniformly high quality die castings by forcing high melting-point metals "uphill" with pneumatic pressure.

I further hope that you now share with me the conviction that a scientific foundation has been laid for the birth of a new industry. I thank you.

MERCURY VAPOR GRID-CONTROLLED TUBES; THEIR ELECTRIC CONTROL BY A PHASE-SHIFTING NETWORK.

BY

J. A. STRELZOFF, Ph.D.,

Scranton-Keystone Junior College, La Plume, Penna.

(Concluded from July issue.)

IV. APPLICATIONS.

1. A Variable A.C. Resistance Load.

The choice of this application was directed by a desire to somewhat amplify the findings of the previous chapter in a more complete examination of the behavior of a transformer connected through a tube (or a combination of tubes) to a variable resistance load.[5]

We shall consider only the single phase case; the connections are shown in Fig. 7.

The supply is an a.c. source connected through a transformer to two grid controlled vacuum tubes, connected in antiparallel. A resistance in the primary represents the load. This arrangement may be used for the regulation of current of an a.c. load and offers the advantage of economy, as there are no inherent heat losses in such an installation due to a varying resistance. The change in the a.c. current is obtained by the change in the time of conduction of the tube from full opening for full load, to complete blocking for no-load.

Through the commutation of the tube, the reactance of the transformer is varied and thus also the load current. In the following we shall consider only one of the tubes present, which does not modify the effect of commutation.

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[5] It has also its practical application in installations where the current form is of small or no importance, such as in the case of pure resistance loads, lighting, heating, etc. . . .

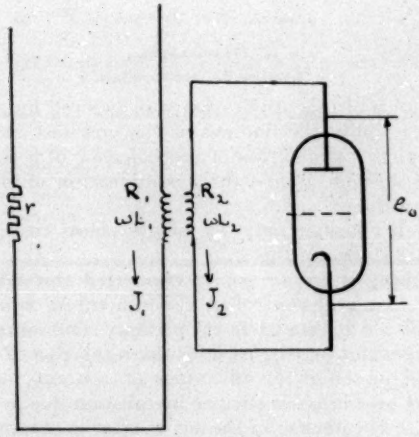
(a) Equations.

The differential equations describing the circuit shown in Fig. 12 and neglecting the capacitance, are

$$e_1 = i_1R + L_1di_1/dt + Mdi_2/dt,$$
$$0 = i_2R_2 + L_2di_2/dt + Mdi_1/dt + e_0,$$

where $R = r - R_1$, and e_0 is the voltage drop across the rectifier. In the following e_0, which is small comparatively to the applied voltage, and therefore its influence on the general treatment is of little importance, is considered as a constant.

FIG. 12.



Change of Variable. Instead of time t it is preferable to have the above equations expressed in function of an angle θ. Then let

$$wt_1 = \theta \quad \text{and} \quad wL_1 = wL_{1s} + wMn_1/n_2,$$
$$wL_2 = wL_{2s} + wMn_1/n_2$$

and

$$e_1 = i_1R + wL_1\, di_1/d\theta + wM\, di_2/d\theta, \qquad (12a)$$
$$0 = i_2R_2 + wL_2\, di_2/d\theta + wM\, di_1/d\theta + e_0. \qquad (12b)$$

The solution [6] of these equations is given by

$$i_1 = A_1 \operatorname{Sin}(\theta - \phi_1) + C_1 e^{\alpha_1 \theta} + C_2 e^{-\alpha_2 \theta}, \qquad (13a)$$

$$i_2 = -e_0/R_2 + A_2 \operatorname{Sin}(\theta - \phi_2) + C_3 e^{-\alpha_1 \theta} + C_4 e^{-\alpha_2 \theta}. \qquad (13b)$$

The first member and the two first members of the right-hand side of eqs. (13a) and (13b) respectively are the steady state solutions of eqs. (12), the rest being the corresponding transient part.

The Evaluation of the Time Constants. α_1 and α_2 may be obtained as follows: Differentiating eqs. (12) and eliminating i_2 we obtain:

$$d^2 i_1/d\theta^2 + (a_1 + a_2)(di_1/d\theta) + a_1 a_2 b i_1 = 0, \qquad (14)$$

where

$$a_1 = R/wL_1 b, \quad a_2 = R_2/wL_2 b, \quad b = 1 - (wM)^2/w^2 L_1 L_2.$$

The characteristic equation of the differential eq. (14) is

$$\alpha^2 - (a_1 + a_2)\alpha + a_1 a_2 b = 0,$$

the solution of which determines the two damping coefficients α_1 and α_2, namely

$$\alpha_{1,2} = (a_1 + a_2)/2 \pm ((a_1 + a_2)^2/4 - a_1 a_2 b)^{1/2}.$$

Substituting in eq. (12a) for currents i_1 and i_2 as defined by eqs. (13a) and (13b) and omitting the steady state members of these equations as well as the impulse (i.e., e_1) the well known equation of the compensation (or equalization) process is found, or

$$(C_1 e^{-\alpha_1 \theta} + C_2 e^{-\alpha_2 \theta})R - wL_1(\alpha_1 C_1 e^{-\alpha_1 \theta} + \alpha_2 C_2 e^{-\alpha_2 \theta}) - wM(\alpha_1 C_3 e^{-\alpha_1 \theta} + \alpha_2 C_4 e^{-\alpha_2 \theta}) = 0.$$

Because this equation must satisfy all values of θ, the parts of the equation of equal damping factor must themselves separately satisfy the equation. This means that:

$$C_1 R - wL_1 \alpha_1 C_1 - wM\alpha_1 C_3 = 0. \qquad (15a)$$

and

$$C_2 R - wL_2 \alpha_2 C_2 - wM\alpha_2 C_4 = 0. \qquad (15b)$$

[6] See: Steinmetz, "Theory and Calculation of Transient Electric Phenomena and Oscillations." Chapter X.

From eqs. 15(a) and (b) we derive

$$C_3 = C_1(R - \alpha_1 wL_1)/\alpha_1 wM = k_1 C_1, \qquad (16a)$$

also

$$C_4 = C_2(R - \alpha_2 wL_2)/\alpha_2 wM = k_2 C_2. \qquad (16b)$$

During the blocking (no-conduction) interval the secondary current $i_2 = 0$; during this interval the transformer's reactance has the value of wL_3, and the primary current is given by the expression:

$$i_1 = + A_3 \operatorname{Sin}(\theta - \phi_3) + C_5 e^{-\beta\theta}, \qquad (17)$$

where $\beta = R/wL_3$. For the conduction interval following a blocking interval, the current is determined by an equation similar to eq. (13a), which for generality may be written as follows:

$$i_1 = A_1 \operatorname{Sin}(\theta - \phi_1) - C_6 e^{-\alpha_1\theta} + C_7 e^{-\alpha_2\theta}. \qquad (18)$$

The constants C_6 and C_7 may be equal or not to C_1 and C_2 respectively depending on the initial conditions.

(b) Evaluation of the Amplitudes A and Phase Angles ϕ of the Steady State Equations.

For a transformer under steady state the following equations may be written:

$$U_1 = J_1 R + J_1 jwL_1 + J_2 jwM, \qquad (19a)$$

$$0 = J_2 R_2 + J_2 jwL_2 + J_1 jwM. \qquad (19b)$$

From eq. (19b)

$$J_2 = - J_1 jwM/(R_2 + jwL_2). \qquad (20)$$

Introducing this expression into (19a) we obtain

$$\begin{aligned} U_1 &= J_1 R + J_1 jwL_1 + J_1(wM)^2/(R_2 + jwL_2) \\ &= J_1 R + J_1 jwL_1 + J_1(wM)^2(R_2 - jwL_2)/(R_2^2 + (wL_2)^2) \end{aligned}$$

and the effective value is

$$\begin{aligned} E_1 = I_1((R + (wM)^2 R^2/R_2^2 + (wL_2)^2)^2 \\ + (wL_1 - (wM)^2 wL_2/(R_2^2 + (wL_2)^2)^2)^{1/2}. \end{aligned} \qquad (21)$$

Therefore

$$\begin{aligned} A_1 = E_1(2/(R + wM)^2 R_2/(R_2^2 + (wL_2)^2)^2 + wL_1 \\ - (wM)^2 wL_2/(R_2^2 + (wL_2)^2)^2)^{1/2}. \end{aligned} \qquad (22)$$

Substituting in eq. (20) the value of J_1 as given by eq. (21) we obtain:

$$J_2 = -U_1 wMj/(RR_2 + R_2 wL_1 j + RwL_2 j - w^2 L_1 L_2 + (wM)^2)$$

of which the effective value is:

$$I_2 = E_1 wM/(R_2 R - w^2 L_1 L_2 + (wM)^2 + (R_2 wL_1 + RwL_2)^2)^{1/2} \quad (23)$$

and therefore

$$A_2 = E_1 wM(2/R_2 R - w^2 L_1 L_2 + (wM)^2 + (R_2 wL_1 + RwL_2)^2)^{1/2}. \quad (24)$$

Similarly

$$A_3 = E_1(2/R_1^2 + (wL_3)^2)^{1/2}. \quad (25)$$

For the phase angle ϕ we obtain: From eq. (25)

$$\tan \phi_1 = (wL_1(R_2^2 - (wL_2)^2) - (wM)^2 wL_2)/(R_1(R_2^2 + (wL_2)^2) + (wM)^2 R_2). \quad (26)$$

From eq. (27)

$$\tan \phi_2 = (R_1 R_2 + (wM)^2 - w^2 L_1 L_2)/(R_1 wL_2 + R_2 wL_1). \quad (27)$$

From eq. (29)

$$\tan \phi_3 = wL_3/R_1. \quad (28)$$

(c) Evaluation of Constants of the Transient State, from the Initial Conditions.

The constants of integration to be evaluated are: $C_1 \cdots C_7$, the time θ_1 at which the discharge begins, θ_2 at which the discharge is finished and θ_3 and θ_4, the zero points of the primary current. They are evaluated as follows:

The process is considered as continuous of a period 2. The current i_1 for any time θ is determined by eq. (13a). The current immediately following the ignition is given by eq. (18). The ignition periodically repeats after a lapse of time $\theta = 2\pi$. At any same time the currents given by eqs. (13a) and (18) are the same, therefore:

$$A_1 \operatorname{Sin}(\theta - \phi_1) + C_1 e^{-\alpha_1 \theta} + C_2 e^{-\alpha_2 \theta} = A_2 \operatorname{Sin}(2\pi + \theta - \phi_1) + C_6 e^{-\alpha_1(2\pi+\theta)} + C_7 e^{-\alpha_2(2\pi+\theta)}.$$

And for this equation to hold for any time θ during the con-

duction interval it is necessary that:

$$C_1 e^{-\alpha_1 \theta} = C_6 e^{-\alpha_1 (2\pi + \theta)} \quad \text{and} \quad C_2 e^{-\alpha_2 \theta} = C_7 e^{-\alpha_2 (2\pi + \theta)}.$$

Therefore

$$C_1 = C_6 e^{-2\pi\alpha_1}, \qquad C_2 = C_7 e^{-2\pi\alpha_2}. \tag{29}$$

At time θ_2, beginning of the blocking period, or end of discharge, the current is defined by eq. (13a) as well as by eq. (17). Therefore the following must hold:

$$A_1 \operatorname{Sin} (\theta_2 - \phi_1) + C_1 e^{-\alpha_1 \theta_2} + C_2 e^{-\alpha_2 \theta_2} = A_3 \operatorname{Sin} (\theta_2 - \phi_3) + C_5 e^{-\beta \theta_2}. \tag{30}$$

At time $2\pi + \theta_1$, θ_1 the time of end of the blocking period the current is defined by eq. (17) or by eq. (19). Thus as before we may write

$$A_1 \operatorname{Sin} (2\pi + \theta_1 - \phi_1) + C_6 e^{-\alpha_1 (2\pi + \theta)} + C_7 e^{-\alpha_2 (2\pi + \theta_1)} = A_3 \operatorname{Sin} (2\pi + \theta_1 - \phi_3) + C_5 e^{-\beta (2\pi - \theta_1)}. \tag{31}$$

Another equation will be given from the following considerations. It may be shown that the steady primary current of transformer connected to an a.c. source and with the secondary closed through a rectifier is necessarily an a.c. current.

Integrating the equation for the primary, as given by eq. (12a), for a complete period, we obtain:

$$\int_0^{2\pi} e_1 d\theta = \int_0^{2\pi} i_1 R d\theta + \int_0^{2\pi} w L_1 di_1 + \int_0^{2\pi} w M di_2.$$

Then if e_1 is an a.c. source the left-hand side of the above equation is equal to zero,[7] also the second and third integrals of the right-hand side of the equation are equal to zero. This is because i_1 and i_2 are periodic functions of period 2π. It follows that

$$\int_0^{2\pi} i_1 R d\theta = 0$$

which means that i_1 is an a.c. current. And therefore we

[7] See, for instance, Malti's, "Electric Circuit Analysis."

may write:

$$(1/(\theta_4 - \theta_3))\left(\int_{\theta_3}^{\theta_2}(C_1e^{-\alpha_1\theta} + C_2e^{-\alpha_2\theta} + A_1 \operatorname{Sin}(\theta - \phi_1))d\theta + \int_{\theta_2}^{\theta_4}(C_5e^{-\beta\theta} + A_3 \operatorname{Sin}(\theta - \phi_3))d\theta\right)$$
$$= (1/(\theta_3 + 2\pi - \theta_4))\left(\int_{\theta_4}^{\theta_1+2\pi}(C_5e^{-\beta\theta} + A_3 \operatorname{Sin}(\theta - \phi_3))d\theta + \int_{\theta_1+2\pi}^{\theta_3+2\pi}(A_1 \operatorname{Sin}(\theta - \phi_1) + C_6e^{-\alpha_1\theta} + C_7e^{-\alpha_2\theta})d\theta\right)\cdots. \quad (32)$$

It is important to know the approximate location of the points θ_3 and θ_4 respectively to the points θ_1 and θ_2, thus for instance if θ_3 is in the discharge and θ_4 in the block interval, the following equation may be written, which determines θ_3 and θ_4, namely

$$C_1e^{-\alpha_1\theta_3} + C_2e^{-\alpha_2\theta_3} + A_1 \operatorname{Sin}(\theta_3 - \phi_1) = 0, \quad (33a)$$
$$C_5e^{-\beta\theta} + A_3 \operatorname{Sin}(\theta_4 - \phi_3) = 0. \quad (33b)$$

Next, from the knowledge that the secondary current $i_2 = 0$ at time θ_2 and θ_1, the following two equations derived from eq. (13b) may be written:

$$C_3e^{-\alpha_1\theta_1} + C_4e^{-\alpha_2\theta} + A_2 \operatorname{Sin}(\theta_1 - \phi_2) - e_0/R_2 = 0 \quad (34a)$$

and

$$C_3e^{-\alpha_1\theta_2} + C_4e^{-\alpha_2\theta_2} + A_2 \operatorname{Sin}(\theta_2 - \phi_2) - e_0/R_2 = 0. \quad (34b)$$

Thus the eleven unknown constants of integration $C_1 \cdots C_7$, $\theta_1 \cdots \theta_4$ are therefore defined by the eleven eqs. (23) to (34), but cannot be evaluated because these equations are of a transcendental form. For practical purposes it is possible by use of simplifications to arrive at the solution of these equations.

It is usually possible to take the origin at the beginning of a discharge, then $\theta_1 = 0$. The angle λ, at which the coördinates of the primary are displaced with respect to

secondary must then be introduced in the equations. The equations are:

$$C_1 e^{-\alpha_1 \theta_2} + A_1 \operatorname{Sin}(\theta_2 - \phi_1 + \lambda) + C_2 e^{-\alpha_2 \theta_2} = A_3 \operatorname{Sin}(\theta_2 - \phi_3 + \lambda) + C_5 e^{-\beta \theta_2}, \quad (30a)$$

$$A_3 \operatorname{Sin}(-\phi_3 + \lambda) + C_5 e^{-2\pi\beta} = A_1 \operatorname{Sin}(-\phi_1 + \lambda) + C_6 e^{-2\pi\alpha_1} + C_7 e^{-2\pi\alpha_2}, \quad (31a)$$

$$C_1 e^{-\alpha_1 \theta_3} + C_2 e^{-\alpha_2 \theta_3} + A_1 \operatorname{Sin}(\theta_3 - \phi_1 - \lambda) = 0, \quad (I)$$

$$C_5 e^{-\beta\theta} + A_3 \operatorname{Sin}(\theta_4 - \phi_3 + \lambda) = 0, \quad (II)$$

$$\begin{aligned}(1/(\theta_4 - \theta_3))\Big(\int_{\theta_3}^{\theta_2} &(C_1 e^{-\alpha_1\theta} + C_2 e^{-\alpha_2\theta} \\ &- A_1 \operatorname{Sin}(\theta - \phi_1 + \lambda))d\theta + \int_{\theta_2}^{\theta_4} (C_5 e^{-\beta\theta} \\ &+ A_3 \operatorname{Sin}(\theta - \phi_3 + \lambda))d\theta\Big) \\ = -(1/(\theta_3 + 2\pi - \theta_4))\Big(&\int_{\theta_4}^{2\pi} (C_5 e^{-\beta\theta} \\ &+ A_3 \operatorname{Sin}(\theta - \phi_3 + \lambda))d\theta \\ &+ \int_{2\pi}^{\theta_3 + 2\pi} (A_1 \operatorname{Sin}(\theta - \phi_1 + \lambda) \\ &+ C_6 e^{-\alpha_1\theta} + C_7 e^{-\alpha_2\theta} + \lambda)d\theta\Big), \end{aligned} \quad (32a)$$

$$C_3 + C_4 + A_2 \operatorname{Sin}(-\phi_2 + \lambda) - e_0/R_2 = 0, \quad (34a')$$

$$C_3 e^{-\alpha_1\theta_2} + C_4 e^{-\alpha_2\theta_2} + A_2 \operatorname{Sin}(\theta_2 - \phi_2 + \lambda) - e_0/R_2 = 0. \quad (34b')$$

Equations (16) and (29) remain unchanged.

V. TESTS.

To verify the conclusions arrived at in the previous chapter a number of tests were performed, first with an air core transformer and next with an iron core transformer. The influence of the iron core can thus be examined. The necessary transformer constants are determined by d.c. measures. The value of wL_1 and wL_2 are determined from the primary and secondary no-load test by the following equations:

$$U_{10} = J_{10}R_1 + J_{10}jwL_1,$$
$$U_{20} = J_{20}R_2 + J_{20}jwL_2$$

and from the above

$$wL_1 = ((E_{10}/I_{10})^2 - R_1^2)^{1/2},$$
$$wL_2 = ((E_{20}/I_{10})^2 - R_2^2)^{1/2}.$$

wM is determined by measuring at no-load of the primary current and secondary no-load potential from the equation.

$$wM = E_{20}/I_0.$$

FIG. 13.

1. Air core transformer. Oscillogram 13 at fully opened tube, shows the primary current i_1, secondary (plate) current i_2 and supply potential e_1. At time θ_1 the plate current is started at time θ_2 the conduction interval is finished.

1. Air Core Transformer.

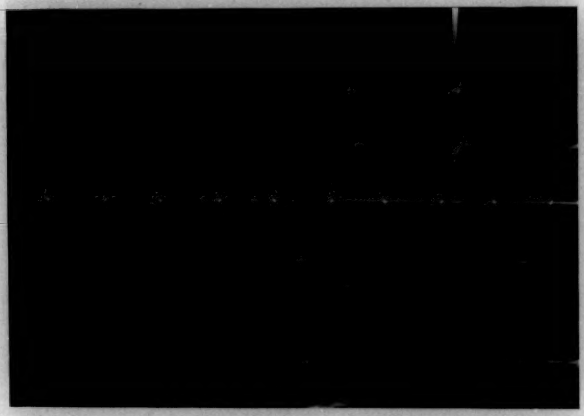
Oscillogram 13 at fully opened tube, shows the primary current i_1, secondary (plate) current i_2 and supply potential e_1. At time θ_1 the plate current is started, at time θ_2 the conduction interval is finished.

Oscillogram 14 shows at fully (or nearly so) closed tube, the primary current i_1, secondary (tube) current i_2 and supply potential e_1. The tube current i_2 is notably smaller and circulates during a much smaller time interval, than in the case of fully opened tube. In the primary current i_1 is also

recognizable, between the time θ_1 and θ_2, the influence of the tube current. The regulation of the primary current through the commutation of the tube current is in this case rather small. The reason for that lies in the light inductance, at no-load, of the air core transformer.

Next we shall examine the above oscillograms with the help of eqs. (30a)$\cdots$(34b′). As these equations are not solvable we shall take one of the unknowns for a scale. Let,

FIG. 14.



for instance, θ_2 be so accepted, then the rest of the unknowns shall be evaluated through θ_2.

The damping of the commutation fields, is known to be great during the transient period. It is therefore admissible to consider that at time θ_2 the members $\epsilon^{-\alpha_1\theta}$ are decayed. Thus introducing the new notation

$$\epsilon = \theta_2 - \phi_2, \qquad \xi = \theta_2 - \phi, \qquad \eta = \theta_2 - \phi_3.$$

We arrive, after simplifications, to the following relation between λ and θ_2.

$$\begin{aligned}\operatorname{Cos}\lambda[&e^{-\beta(2\pi-\theta_2)}(-1/k_2A_2\operatorname{Sin}\epsilon + A_1\operatorname{Sin}\xi\\ &- A_3\operatorname{Sin}\eta) - A_3\operatorname{Sin}\phi_3 - 1/k_1A_2\operatorname{Sin}\phi_2\\ &- (A_2\operatorname{Sin}\epsilon/e^{-\alpha_2\theta_2})(1/k_2 - 1/k_1) + A_1\operatorname{Sin}\phi_1]\\ +\operatorname{Sin}\lambda[&e^{-\beta(2\pi-\theta_2)}(-1/k_2A_2\operatorname{Cos}\epsilon + A_1\operatorname{Cos}\xi\\ &- A_3\operatorname{Cos}\eta) + A_3\operatorname{Cos}\phi_3 + 1/k_1A_2\operatorname{Cos}\phi_2\\ &+ (A_2\operatorname{Cos}\epsilon/e^{-\alpha_2\theta_2})(1/k_2 - 1/k_1) - A_1\operatorname{Cos}\phi_1]\\ &+ (e_0/R_2)(1/k_1(1 - 1/e^{-\alpha_2\theta_2}) - 1/k_2e^{-\alpha_2\theta_2}] = 0. \quad (35)\end{aligned}$$

From the above equation is determined, then from eqs. (16), (34a′) and (34b′) the constants C_1, C_2, C_3 and C_4 are evaluated, and finally from eq. (30a) the value of the constant C_5 is obtained. As one unknown was taken from the oscillogram, and all the other unknowns were determined in function of that taken from the oscillogram, it is possible to dispense with one of the equations. We shall therefore not use equations I and II for the determination of θ_3 and θ_4.

From eqs. I and II knowing the values of

$$R = 5.8 \text{ ohm} \qquad e_0 = 15 \text{ volts} \qquad E_1 = 116 \text{ volts},$$

we derive

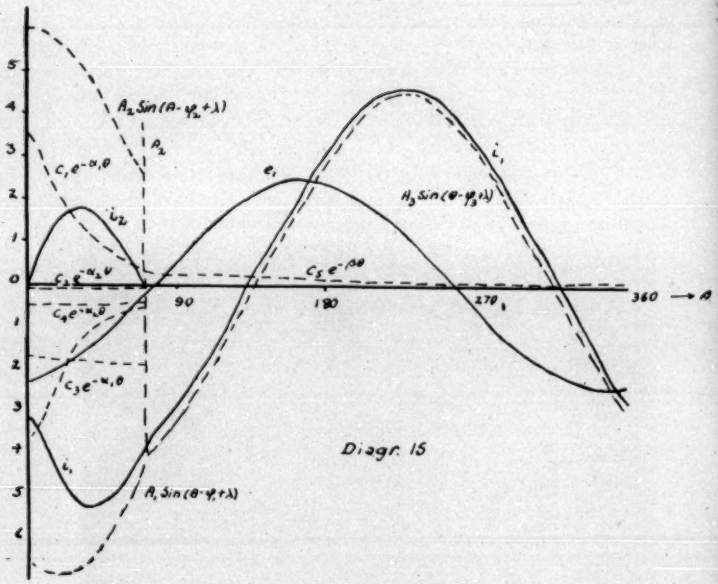
$R = 5.8$ ohm	$R_1 = 9.16$ ohm	$R_2 = 2.58$ ohm
$\alpha_1 = 1.742$	$\alpha_2 = 0.134$	$b = 0.363$
$A_1 = 5.15$	$A_2 = 1.8$	$A_3 = 4.55$
$\phi_1 = 32°$	$\phi_2 = -158°$	$\phi_3 = 63°.$
$k_1 = -0.96$	$k_2 = 3.82$	

Case (*a*). Next we shall evaluate the process with the tubes nearly fully blocked. Measuring on the obtained diagram $\theta_2 = 70°$ (as before, θ_1 is taken for the zero point). From eq. (35) $\lambda = -69° 30'$. As in this case, the approximation made in the derivation of eq. (35), namely, that $e^{-\alpha_1\theta}$ is at the time θ_2, decayed, is not justified, because of the short period of conduction, therefore the evaluation of λ is in this case inaccurate. Taking the value of λ also from the diagram, or $\lambda = -73°$, with this value we evaluate

$$C_1 = +9.95, \qquad C_2 = -0.27, \qquad C_3 = -9.55,$$
$$C_4 = -1.03, \qquad C_5 = 1.58.$$

With these values we draw Diagram 15 which follows pretty closely Diagram 14.

FIG. 15.



The following table gives the values of interest taken from oscillogram and from the diagram built with the calculated values.

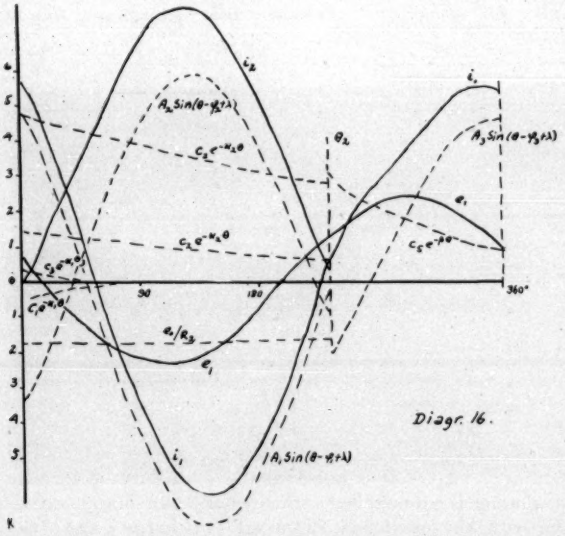
	Measured	Constructed
Conduction period		
J_1 max	5.15	5.20
J_2 max	1.8	1.8
Blocking period		
J_3 max	4.55	4.50

Case (*b*). We shall now evaluate the behavior of the currents the tubes being fully opened. From oscillogram 13, we take the value of $\theta_2 = 228°$ and by eq. (35), the value of

$\lambda = 172° 30'$ (on the oscillogram $\lambda = 165°$). The difference may be explained as due to the following.

At the fully opened tube the ignition starts when the secondary transformer potential reaches the ignition potential. The lapse of the process depends thus on the value of the ignition potential. This, especially for grid controlled tubes,

FIG. 16.



is higher than the firing potential (the potential at which the anode may be fired). We cannot then, through the equations which depend on the firing potential, describe the process very correctly. With the corrected value of (as taken from the oscillogram) we obtain:

$$C_1 = -1.025, \quad C_2 = +3.17, \quad C_3 = 1.08,$$
$$C_4 = 12.15, \quad C_5 = 59.5.$$

These values serve to draw Diagram 16, which follows very

closely Diagram 13. The following table gives a comparison between the values taken from the oscillogram and from Diagram 16.

	Measured	Constructed
Conduction interval		
J_1 max	5.4	6.00
J_2 max	6.8	7.7
Blocking interval		
J_3 max	5.00	5.4

The closeness of the results is gratifying. It is to be taken into account that the value of θ_2 is measured with a certain uncertainty, also the voltage drop through the tube is only approximately correct.

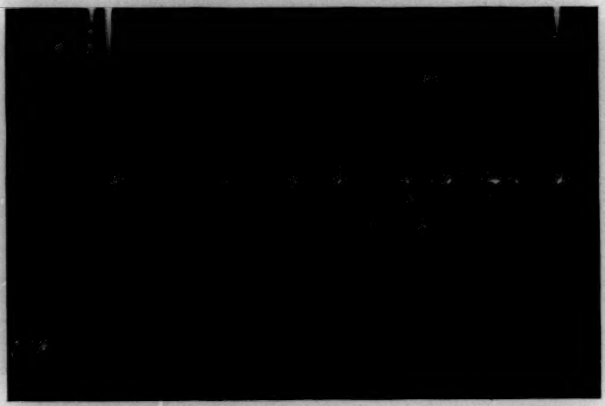
2. Iron Core Transformer.

Figure 17 shows an oscillogram of a test with an iron core transformer connected as shown in Diagram 7. The curves are, i_1—primary current, i_2—secondary or plate current and e—supply potential. In the form of the primary current, as well in the conduction as in the blocking period it is to be noticed, that the steady state sinusoidal part of the current is strongly marked. One could expect that the steady state part, due to the great size of the $n\phi$-load reactance of the iron core, would be completely suppressed during the period of blocking. That that is not so is due to the following: The transformer is not supplied with a definite flux, but in accordance with the previously discussed "discharge" and "a.c. behavior" conditions in the blocking period, a definite primary current is forced upon it, which no secondary winding can hold in equilibrium. Because of that the saturation of the iron is pushed to a point above the knee of the magnetization curve, and therefore the inductance greatly declines. It may be observed in the behavior of the potential e in Diagram 17. During the blocking period:

$$e = i_1 R_1 + wL_1 \, di_1/d\theta,$$

the ohmic drop is very small, and the inductance is practically equal to the quotient of the applied potential and the current change, the drop of potential at the point a (see Diagram 17) though the corresponding current is decreasing, shows that at the time the inductance greatly declines. The evaluation of the transformer inductance from the oscillogram, gives, at the point a, a value about 10 times its value at no-load. From this diagram, the Diagram 20 is constructed, giving $i_1 + i_2$. As the transformer used was of 1 : 1 ratio, so this value,

FIG. 17.

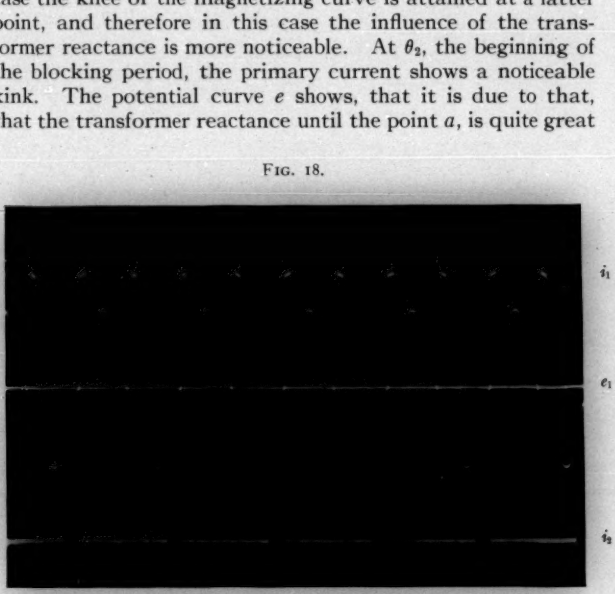


Iron core transformer.

leakage being neglected, is proportional to the resultant ampere turns. In the above diagram the induction of 10,000 max./cm.^{2} is drawn against the maximum value of I_{10} max. of no-load current. It shows that the iron must be very highly saturated. Further it is to be noted, that the magnetizing is no more symmetrical but is one-sided and falls in the region of higher induction. Because of that the time rate of the corresponding flux variation is light, i.e. the transformer inductance is very small.

Oscillogram 18 shows the same test for a smaller load which is obtained by lowering the primary potential. In this case the knee of the magnetizing curve is attained at a latter point, and therefore in this case the influence of the transformer reactance is more noticeable. At θ_2, the beginning of the blocking period, the primary current shows a noticeable kink. The potential curve e shows, that it is due to that, that the transformer reactance until the point a, is quite great

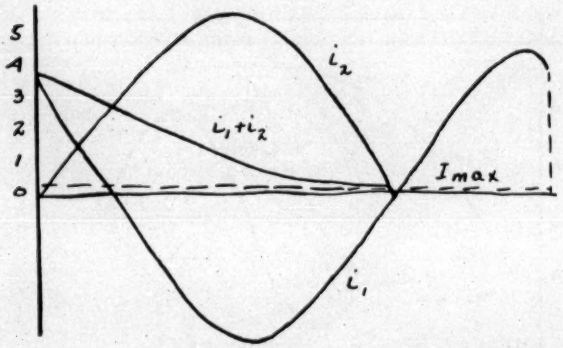
FIG. 18.



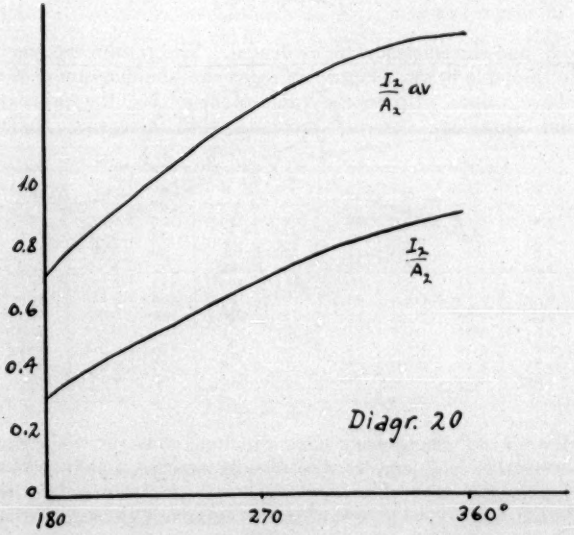
(same scale as Diagram 17). Only below a it begins to decrease, and as a result the current rises again strongly.

At greater blocking of the tube the influence of the iron is still more noticeable, as may be seen from Diagram 19. As before this diagram gives the primary and secondary currents as well as the supply potential.

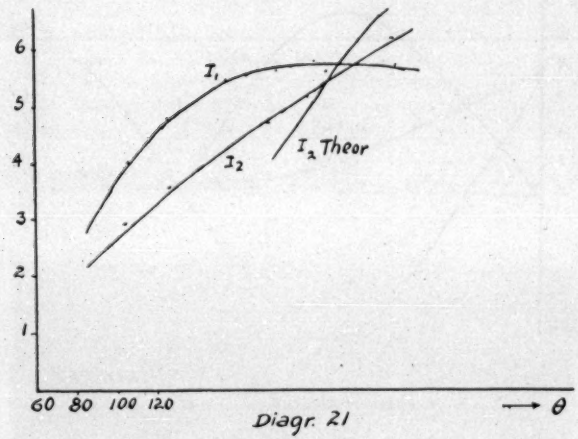
During the tests with the iron core transformer the following data were measured. Primary current I, rectifier current I_2, supply potential E_1, load potential (a pure resistance load) E, power supply w_1, power at the load w and θ_2 time length of the conduction interval. The power factor,



Diagr. 19



Diagr. 20



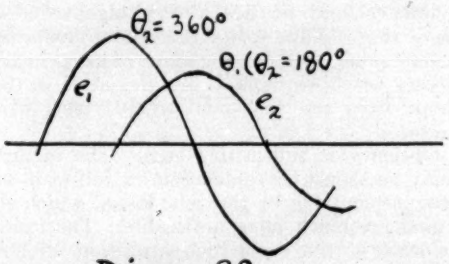
Diagr. 21

p.f., and the efficiency are evaluated. The results are given in the table below. Figure 23 represents the diagram of the above values. Up to the value of $\theta_2 = 180°$ the primary and secondary currents increase with increasing angle.

I	I_2	E_1	E	W_1	W	θ_2	p.f.	
1.0	0.00	117.0	16	41	29.5	0	0.35	72
1.5	0.52	117.0	42	114	87.5	84	0.65	76.7
1.7	0.7	117.0	48	134	104	96	0.67	78.0
2.00	1.25	116.5	63	192	158	114	0.78	82.0
2.1	1.26	116.5	60.0	181	150	114	0.754	82.0
2.05	1.56	116.0	68.0	217	185	128	0.81	85.9
2.3	1.68	116.7	72	272	240.5	182	0.893	88.4
2.6	2.11	116.2	74.1	295	265	214	0.905	90.0
2.8	2.12	116.0	73.5	300	270	216	0.915	90.0
2.81	2.25	116.0	78	315	290	258	0.95	92.0
2.85	1.19	116.5	58	175	144	108	0.75	82

Beyond 180° the primary current remains constant, while the secondary (tube) current continues to increase, which checks the theory. The theoretical value of i_2 is shown by the dotted line. The influence of the approximations is to be

observed in the fact that the dotted line (i_2) lies first below and then above the measured value. The agreement between



Diagr. 22

the theoretical and the measured values lies in the region from 200° to 220°, at the best. This is also the region in

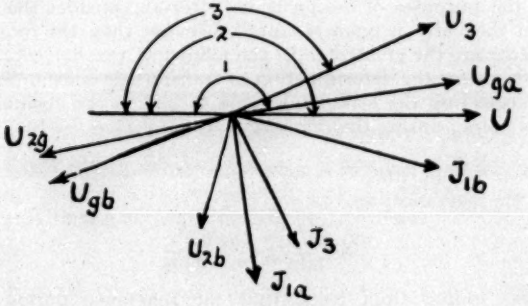


fig. 23

which, as is proved somewhere else in this paper, it is best to operate the tube. As a result of the simplifications (neglecting the voltage drop) the currents are about 7 per cent. smaller

than calculated. The reached approximation is sufficient for purposes of design.

The power factor increases with the increase of the conduction interval and reaches a very high value at points above $\theta_2 = 180°$. This shows that the transformer inductance is very small, and that the shape of the primary current curve is very nearly sinusoidal, as a deviation of the current wave shape from the sinusoidal would result in a poorer power factor.

The efficiency is sufficiently high. The incurred losses are, as may be shown by calculation, at full load, for half of their value accountable by the tube losses, which at the low voltage used are much more noticeable. The iron losses of the transformer are due to the high saturation, not abnormally high, for at an unsymmetrical magnetizing the actual flux variations are small.

3. Transformer Data.

The influence of the inductance in transformers, due to the variation of the current, complicates the process still more. For the purposes of design it is better to consider the case when the valve is open circuited, because then the required currents are the greatest. In the following, we shall establish equations for the determination of transformer constants.

Neglecting the leakage, let $b = 0$. Then the coefficients of damping, during the discharge, are

$$\alpha_1 = \infty \qquad \text{and} \qquad \alpha_2 = 1/(wL_1/R + wL_2/R_2)$$

and the reactances are

$$wL_1/wL_2 = (n_1/n_2)^2,$$
$$wL_1 = n_1 wM/n_2.$$

It was found, from tests, that the reactance during the blocking period, wL_3, is on account of high saturation, equal to approximately 1/100 of the no-load value. During the discharge the saturation is somewhat smaller.

In the majority of transformers the no-load current is about 10 per cent. of the full-load current, i.e. R/wL_1 (normal) $= 0.1$. Thus if it is estimated (which is about the usual value in practice) then $wL_1 = 0.05 wL_1$ (normal), i.e. the

average transformer reactance to be 5/100 of its no-load value, then $wL_1 = 0.05wL_1$ (normal) $= 0.5R$. The ohmic component of the short-circuit voltage is usually very small. Taking it to be 2.5 per cent., then for equal weight of copper of the primary and secondary windings

$$R_1 = R_2(n_1/n_2)^2 = 0.0125R$$

and thus we may write

$$R_1 \ll wL_1, \qquad R_2 \ll wL_2.$$

$\alpha_{1,2}$ are evaluated from the equation

$$\alpha_{1,2} = (a_1 + a_2)/2 + ((a_1 - a_2)^2/4 - a_1a_2b)^{1/2},$$

where as before:

$$a_1 = R/wL_1b, \quad a_2 = R_2/wL_2b \quad \text{and} \quad b = 1 - (wM)^2/w^2L_1L_2.$$

Substituting the corresponding values we obtain $\alpha_2 = 0.0183$, or very small. Therefore the approximation of $e^{-\alpha_2\theta_2} = 1$ made previously, is justified. This approximation is so much closer, the less the discharge period exceeds 180°. From eqs. (16)

$$k_1 = -1, \qquad k_2 = 1.3$$

and from eqs. (21)–(25) we obtain

$$A_1 = \sqrt{2}\,E_1/R, \qquad A_2 = n_1E_1\sqrt{2}/n_2R$$
$$A_3 = \sqrt{2}\,E_1/R = A_1 = A, \qquad \phi_1 = \phi_3 = 0, \qquad \phi_2 = -180°.$$

From $\beta - R/wL_3$ it is found that β is approximately equal to 10. We can also consider that at time θ_2, $e^{-\beta\theta}$ has died out. With the above values eq. (35) becomes

$$\text{Sin}\ (\theta_2 - \lambda) = \text{Sin}\ \lambda \tag{35a}$$

and from the eqs. (16), we obtain the values for the constants, namely:

$$C_1 = C_2 = C_3 = C_5 = 0,$$
$$C_4 = e_0/R_2 + A_2\ \text{Sin}\ (\theta_2 + \lambda).$$

And the equations for the currents become:

$$i_1 = A\ \text{Sin}\ (\theta + \lambda) \tag{36a}$$

$$i_2 = -A_2\ \text{Sin}\ (\theta + \lambda) + A_2\ \text{Sin}\ (\theta_2 + \lambda). \tag{36b}$$

Equation (36a) holds for the discharge as well as for the blocking period. The primary current is thus a pure sine current, independent of the time interval of the discharge period. That is, in so far as the approximations and hypotheses, especially the high magnetic saturation during the blocking period, are fulfilled. The secondary current is composed of a sine element, on which, during the period of discharge is superimposed a d.c. component.

Effective value of the primary current is $I_1 = E_1/R$. The effective value of I_2 is found by eq. (36b)

$$I_2 = ((1/2\pi) \int_0^{\theta} (- A_2 \operatorname{Sin} (\theta + \lambda) + A_2 \operatorname{Sin} (\theta_2 + \lambda))^2 d\theta)^{1/2}$$
$$= A_2(1/2\pi(- 3 \operatorname{Sin} \lambda \operatorname{Cos} \lambda + (\operatorname{Sin}^2 \lambda - 0.5)\theta_2)^{1/2}. \quad (37)$$

The peak value I_2 (peak) of the rectified current, which is of importance for the evaluation of the rectifier output, depends on the time interval of the discharge period.

$$I_2 \text{ (peak)} = A_2 + A_2 \operatorname{Sin} (\theta_2 + \lambda). \quad (38)$$

The eqs. (37) and (38) are shown in Diagram 21, giving the relations $I_2/A_2 = f_1(\theta_2)$ and $I_2 \text{ (peak)}/A_2 = f_2(\theta_2)$.

It can be seen that the effective and the peak values of the secondary current increase when the discharge period exceeds 180°. At $\theta_2 = 360°$ the first attains a value 2.5 times and the second 2 times their respective values at 180°, while the primary current remains constant. This presupposes, that the saturation of the iron core during the blocking period must be so great, that the transformer reactance may be neglected in comparison with the resistance. This supposition is fulfilled, when the primary current is sufficiently large at the extinction of the discharge period, i.e. when the extinction does not take place in the neighborhood of the zero point.

It is thus advisable to operate the tube with a conduction period of such a time length that the iron be sufficiently saturated, so that the current demand by the transformer and tubes be not unnecessarily great.

The optima time length of the conduction period for a fully opened valve may be determined as follows: The tube

begins to fire (ignites), when the secondary transformer potential $-U_2 = J_1 jwM$ attains the value e_i = potential of ignition of the tube. Thus $U_i = -J_1 jwM$. Let the zero point for the primary be again the zero point of the primary current, while in the general equations, the ignition point be chosen as the origin, then

$$e_i = wMA \text{ Sin } (\theta_1 - 90°) = (n_2 wL_1 \sqrt{2}\, E_1 \text{ Cos } \theta_1)/n_1 R.$$

As before, let $wL_1 = aR (a = 0.1)$, then

$$\text{Cos } \theta_1 = -e_i n_1/\sqrt{2}\, E_1 a n_2.$$

θ_1 – thus varies between 90 and 180 degrees as shown in Fig. 22. The ignition starts so much sooner, the sooner the secondary potential gets to be positive ($\theta_1 = 90°$) and so much later at its peak value ($\theta_1 = 180°$). The time interval of the conduction period is then by eq. (35): $\theta_1(90°) = 360°$ and $\theta_1(180°) = 180°$. The ignition begins thus so much earlier, the smaller is the potential of ignition, the greater the conversion factor and the greater the inductance of the transformer in comparison to the load resistance.

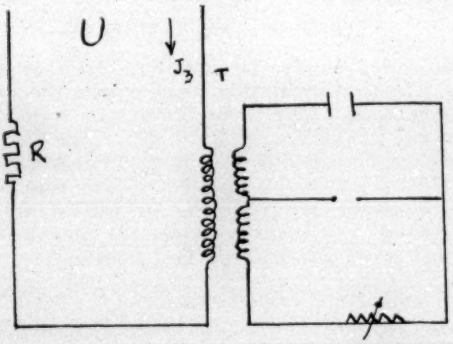
4. Grid Control.

In a blocked tube the primary current J_{1a} is, about at 90°, relative to the supply potential U. The secondary transformer potential U_{2a} leads it by 90°. For the tube to be blocked, the grid potential U_{ga} must be at about 180° relative to the anode potential. If the tube is conducting through more than 180°, then primary current J_{1b} is nearly in phase with the supply potential U, because then the transformer inductance, as shown above, because of the high saturation of the iron, is very small. The secondary potential then takes the position U_{2b}. It can be shown, that to avoid an unnecessary big demand of current from the tube and the transformer, it is advisable to make the conduction period not in excess of 180°. Then it is sufficient to have a grid potential at an angle as shown in U_{gL}. The range of the change of the grid potential is then given by the angle 1. By the use of a phase shifter, as shown in Fig. 3, on the supply potential, the range of the regulation is in this case shown by the angle 2. If that does not correspond closely

enough with the angle 1, then the connection may be re-arranged as shown in Fig. 24.

The phase shifter transformer is then connected to supply potential through a resistance R. As the grid transformers are only lightly charged by the grid, the primary current is essentially a no-load current and by insertion of the resistance R takes the position of J_3. Its primary potential is then

FIG. 24.



given by U_3. The range in which the grid potential may vary in this case is given by the angle 3 which for purposes of design approaches sufficiently the angle 1.

VI. SUMMARY.

A series transformer with an iron core, with the secondary winding closed through a grid controlled tube, may be used to gradually (without step-by-step) regulate the power supplied to a network, connected to an a.c. source. At fully blocked tube, the high inductance of a transformer at no-load throttles the load current. When the tube is operated fully conducting, then through the transient operation the primary current of the series transformer is a pure a.c. current; the iron core, even during the blocking period of the tube, is so highly saturated, and thus the transformer inductance is so small, that the primary current remains sinusoidal and to all

practical purposes is proportional to the load resistance, even if the tube operates intermittently. Also, in all the steps between full conduction and full blocking of the tube, the primary current is a pure a.c. current even if not a pure sine a.c. current.

The time interval of the conduction period may exceed 180° (theoretically up to 360°). An increase beyond 180° is not justifiable, as it has no influence on the primary current, as long as the rectified current increases. It is preferable to operate with an interval of conductivity of 200 to 220 degrees, at which a sufficiently high saturation of the iron is obtained, while the tube's current is not unnecessarily great.

ACKNOWLEDGMENT.

The author desires to express his gratitude to Dr. R. L. Richards for the considerable time he so generously gave in helping to obtain the oscillograms for the experimental check of theoretical conclusions; to Professor F. Bedell, for the use of the oscilloscope of his design with which the oscillograms 8, 9, and 10 were obtained; and finally to Professor V. Karapetoff under whom the author has studied for the last three years.

ITHACA, N. Y., U. S. A.,
June, 1934.

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25 Determinations on Cast Iron in 25 Minutes.—FRANK J. OLIVER. (*Iron Age*, Vol. 139, No. 20.) Spectrographic analysis of metals has been used as a qualitative check for years, and as a research laboratory technic it has been known for over a hundred years. The method is a regular tool of astronomers in identifying the elements in distant planets. But only in the past year have the chemico-physical phenomena of the variations in intensity of light emitted by incandescent vapors of metallic elements been applied in the ferrous foundry industry as a quantitative measure. This was accomplished through the cooperative development work of the Campbell, Wyant & Cannon Foundry Co. and the University of Michigan. In the spectrographic method, a high frequency spark is struck between two small electrodes of the material being examined and the light emitted therefrom is passed through the slit of a spectrograph. This instrument contains in its optical system a prism that spreads out the band of diffracted light so that it can be photographed as vertical black lines of varying degrees of density. Each element present in the sample has a characteristic line or lines which can be readily identified. The density of these lines varies according to the amount of the element present and the variations can be measured by means of an instrument known as the densitometer. Through the use of special charts and scales the density can be converted directly to per cent. of the element present. The application of the apparatus in the foundry, when reduced to a routine basis requires only a normal amount of intelligence, and the technic is extremely fast.

R. H. O.

V.
19

MEDAL DAY MEETING.

The annual Medal Day Meeting of The Franklin Institute was held in the Hall of the Institute on the afternoon of Wednesday, May 19, 1937, at 3:30 o'clock. The meeting was called to order by the President, Mr. Philip C. Staples. He announced that all awards recommended by the Committee on Science and the Arts during the current Institute year would be made at this time.

Award of Longstreth Medals.

To Dr. Emile Monnin Chamot, Professor of Chemistry, Cornell University, Ithaca, New York. Dr. Joseph S. Hepburn, sponsor. The president called upon Dr. Hepburn.

Dr. Hepburn: "Mr. President, the Board of Managers of The Franklin Institute upon recommendation of its Committee on Science and the Arts, has awarded an Edward Longstreth Medal to Dr. Emile M. Chamot, Professor of Chemistry, Cornell University, 'In consideration of his meritorious work in the field of microchemical analysis.'

"This medal was founded in 1890 in honor of Edward Longstreth, former member of the Board of Managers of The Franklin Institute."

The President presented the medal as follows: "Dr. Chamot, by power vested in me as President of The Franklin Institute, I have the honor to present to you the Edward Longstreth Medal."

Dr. Chamot responded: "Thank you. I am deeply appreciative of this honor and am particularly pleased that The Franklin Institute should deem it worthy of consideration that microchemistry is to be regarded as a science and an art."

To Mr. Richard T. Erban, Consulting Engineer, New York City. Mr. C. D. Galloway, sponsor.

The President called upon Mr. Galloway.

Mr. Galloway: "The Board of Managers of The Franklin Institute, on recommendation of its Committee on Science and

the Arts, has voted a Longstreth Medal to Mr. Richard T. Erban, Consulting Engineer, New York City, 'In consideration of the invention and development of the Transitorq, a practical and useful variable speed transmission unit.'"

The President presented the medal as follows: "Mr. Erban, in accordance with the citation which was just read, I am delighted to present to you the Longstreth Medal."

Mr. Erban responded: "I wish to express my gratitude and appreciation for this great honor which you pay me."

To Mr. John S. Haug, Consulting Gas Engineer, United Engineers and Constructors, Inc., Philadelphia. Mr. W. H. Fulweiler, sponsor.

The President called upon Mr. Fulweiler.

Mr. Fulweiler: "Mr. President, the Board of Managers has sanctioned the presentation of a Longstreth Medal to Mr. John S. Haug, Consulting Gas Engineer of the United Engineers & Constructors, Inc., Philadelphia, 'In consideration of the invention and development of an improved type of mechanically clinkered water gas generator.'

"Mr. President, may I call to the attention of the meeting the fact that on July 7, 1886, the Committee on Science and the Arts recommended the award of an Elliott Cresson Gold Medal to Professor Thaddeus S. C. Lowe, 'For his great service to the cause of gas-lighting in connection with his water-gas process, and for his improvements in the manufacture of fuel-gas, and of apparatus for utilizing the same for a variety of purposes.'"

The President presented the medal as follows: "It gives me great pleasure to present this Medal to a fellow citizen. The interesting point regarding the award to Professor Lowe and the one made today to Mr. Haug is that Mr. Haug is a grandson of Professor Lowe and his Medal today is bestowed because of his invention and improvements on the original apparatus of Professor Lowe."

Mr. Haug responded: "Thank you very much, Mr. President. I appreciate the honor."

To Mr. Harold Sinclair, Director, Hydraulic Coupling and Engineering Company, Limited, Middlesex, England. Mr. F. H. Rogers, sponsor.

The President called upon Mr. Rogers.

Mr. Rogers: "Mr. President, I have the honor to present a traveler for the Edward Longstreth Medal. The Board of Managers of The Franklin Institute, in accepting the recommendation of its Committee on Science and the Arts, has made such an award to Mr. Harold Sinclair, Director, Hydraulic Coupling and Engineering Company, Ltd., Middlesex, England, 'In consideration of the adaptation of the constant speed Footinger type hydraulic coupling to the variable speed requirements of industrial applications.'

"Mr. Sinclair has made the long journey from England to be present in person to receive this deserved honor."

The President presented the medal as follows: "I can't imagine how a son of England could leave his country at this particular time. We thank you indeed Sir and want you to know we appreciate the long journey you have taken to be with us today."

Mr. Sinclair responded: "I wish to express my very deep appreciation and gratitude of this award by The Franklin Institute and to say a word in defense of my action in leaving my country at this time. The extenuating circumstances connected with my visit here seem to warrant it in as much as I have come to attend my own coronation."

The President: "We thank you for the effort you have made to be here. Your presence has added much to the interest of our Medal Day exercises."

To Mr. Herbert L. Whittemore, Chief, Engineering Mechanics Section, National Bureau of Standards, Washington. Mr. W. P. Valentine, sponsor.

The President called upon Mr. Valentine.

Mr. Valentine: "The award of the next medal is made for the invention and development of the Proving Ring. This work was done by two gentlemen, who took out patents jointly on the work which was the result of their efforts. Unhappily, before the invention was presented to the Committee on Science and the Arts, one of the collaborators, Captain Serge N. Petrenko, died. This was in 1931.

"Since then, the other gentleman has carried on the work alone and has made further developments. In the name of

the Board of Managers I present to you Mr. Herbert L. Whittemore, Chief, Engineering Mechanics Section, Bureau of Standards, Washington, D. C., to receive a Longstreth Medal, 'In consideration of his part in the invention and development of the Proving Ring for the direct checking of calibrations of testing machines.'"

The President presented the medal as follows: "Mr. Whittemore, we are very glad to honor *you* for the knowledge and skill which you have expended in perfecting this invention, and regret that your co-worker cannot stand beside you today to share in this well-deserved recognition of your labors."

Mr. Whittemore: "Thank you, Mr. President."

AWARD OF HENDERSON MEDAL.

To Dr. Rupen Eksergian, E. G. Budd Manufacturing Company, Philadelphia. Mr. H. H. Quimby, sponsor.

The President called upon Mr. Quimby.

Mr. Quimby: "Mr. President, acting upon the recommendation of its Committee on Science and the Arts, the Board of Managers of The Franklin Institute, has awarded a George R. Henderson Medal to Dr. Rupen Eksergian, the E. G. Budd Manufacturing Company, Philadelphia, 'In consideration of his contributions to Railway Engineering and his accomplishments in the field of railway locomotive and car design.'

"The Henderson Medal was founded in 1924 by the widow of an honored member of our Board of Managers and is awarded for inventions or discoveries in the field of railway engineering."

The President presented the medal as follows: "Dr. Eksergian, I am sure you are proud to be signalled out for this particular Medal, for it was founded in honor of a man whose name and fame were widespread in railway engineering circles."

Dr. Eksergian responded: "I greatly appreciate this award of the Henderson Medal particularly because Mr. Henderson was a power in railway engineering and also that I should be signalled out as a representative in the group of colleagues who are working along these lines, to receive this honor."

V. 19

AWARD OF LEVY MEDAL.

To Inge Lyse, Professor of Engineering Materials, Lehigh University, Bethlehem, Pennsylvania. Captain H. B. Ely, sponsor.

The President called upon Captain Ely.

Captain Ely: "Mr. President, the Louis Edward Levy Medal was founded in 1923, in honor of a long-time member of the Board of Managers, and is awarded each year to the author of a paper of especial merit, published in the JOURNAL OF THE FRANKLIN INSTITUTE. The Board of Managers has voted the award of the Levy Medal to Inge Lyse, Professor of Engineering Materials, Lehigh University, 'For his series of papers on "A Study of the Quality, the Design and the Economy of Concrete" published in the April, May, June and July issues of the JOURNAL of the Institute for 1936.'"

The President presented the medal as follows: "Professor Lyse, through the pages of our JOURNAL your work is well-known to the members of The Franklin Institute. We are delighted to have this opportunity to honor you in person today."

Professor Lyse responded: "I appreciate very highly the award of this medal. I take it as a token of encouragement to science in educational circles and as an endorsement of public support to research activities at Lehigh University."

AWARD OF POTTS MEDAL.

To Dr. John Clyde Hostetter, Vice President, Hartford-Empire Company, Hartford, Connecticut. Mr. J. D. Lee, Jr., sponsor

The President called upon Mr. Lee.

Mr. Lee: "Mr. President, I have the honor to present to you Dr. John C. Hostetter, Vice President, Hartford-Empire Company, Hartford, Connecticut, as the recipient of the Howard N. Potts Gold Medal which was founded by will in 1906 and is awarded for distinguished work in Science and Arts. It is awarded by the Board of Managers to Mr. Hostetter, 'In consideration of the combination of technical understanding and executive ability which has enabled him to direct the application of glass to such diversified new uses as a

200-inch telescope disc and saucepans that can be used above an open flame.'"

The President presented the medal as follows: "Dr. Hostetter, your ingenuity has not only increased the means of obtaining greater scientific knowledge, but has also added to the daily comforts of us all. We are most appreciative."

Dr. Hostetter responded: "Mr. President: In expressing my very deep appreciation for this honor, may I say that I regard this more as a tribute to my former colleagues whose ability, hard work and perseverance have made these accomplishments possible. In that spirit and on their behalf, I would like to accept this award today."

AWARD OF THE CRESSON MEDALS.

To Dr. Carl David Anderson, California Institute of Technology, Pasadena, California. Dr. Thomas D. Cope, sponsor.

The President called upon Dr. Cope.

Dr. Cope: "Mr. President, the Elliott Cresson Gold Medal is one of the oldest and best known awards of The Franklin Institute. It was founded in 1848 and is awarded for discovery or original research, adding to the sum of human knowledge.

"The Board of Managers of The Franklin Institute has voted a Cresson Medal to Dr. Carl D. Anderson, California Institute of Technology, Pasadena, California, 'In consideration of his discovery of the Positron.'

"Dr. Anderson has signified his pleasure in receiving this well-deserved recognition by flying East to be with us this afternoon."

The President then made the following statement: "Dr. Anderson signified his pleasure in receiving the medal by planning to fly East to be with us today. Unfortunately he was detained and is unable to be with us in person."

The President then read a telegram from Dr. Anderson stating that his trip was interrupted by dust storms in the West.*

* Dr. Carl D. Anderson, who was delayed on his trip to Philadelphia by dust storms in Utah, continued his travel by train and arrived here on Monday, May 24. The Cresson Medal was presented to him in person in the office of the Secretary and an informal luncheon was given in his honor.

To Dr. William Bowie, United States Coast and Geodetic Survey, Washington, D. C. Dr. C. B. Bazzoni, sponsor.

The President called upon Dr. Bazzoni.

Dr. Bazzoni: "Mr. President, the Committee on Science and the Arts has recommended to the Board of Managers the award of an Elliott Cresson Gold Medal to Dr. William Bowie, retired Chief of the Division of Geodesy, United States Coast & Geodetic Survey, Washington, D. C., 'In consideration of his contributions to the science of geodesy, particularly with reference to the theory of isostasy, the application of which he has extended to problems in general geophysics and geology.' Dr. Bowie is one of a small group who have appied the principles of physics and engineering to the problems of geology. In view of Dr. Bowie's genius it is not surprising that he has made very considerable progress in this new field."

The President presented the medal as follows: "Dr. Bowie, there is always an added pleasure for The Franklin Institute to pay honor to one in the service of the Government. We know of the devoted efforts put forth by the men in the Bureaus in Washington, and welcome this opportunity to pay public tribute to you, one of the leaders of these specialized groups of scientific workers."

Dr. Bowie responded: "Mr. President, I deeply appreciate this honor granted to me today by your great institution. I shall cherish memory of this day and also shall treasure this beautiful medal. I have known it as one of the great awards of this country.

"It is rather pleasant to have Philadelphia honor the Coast and Geodetic Survey, for our first director, Frederick R. Hassler was from Philadelphia. If it were not for him, the Coast and Geodetic Survey would not have had such a brilliant career."

To Mr. Jacques Edwin Brandenberger, Neuilly-sur-Seine, France. Mr. Lionel F. Levy, sponsor.

The President called upon Mr. Levy.

Mr. Levy: "I present to you in absentia, Mr. Jacques Edwin Brandenberger, a native of Switzerland residing in France, who has been awarded an Elliott Cresson gold medal by the Board of Managers of The Franklin Institute, 'In

consideration of his invention and development of the process of manufacture of continuous transparent sheets of regenerated cellulose which have found a widespread use in industry.'

"Mr. Brandenberger was unable to make the trip to receive this medal in person. He has written, however, to express his sincere appreciation of this tribute to his work and to inform us that his government has sent its Consul in Philadelphia to receive the award. I present the acting Consul for Switzerland in Philadelphia, Mr. Maurice Rohrbach.

The President presented the medal as follows: "Mr. Consul, we deeply appreciate your kindness in coming here to receive this Medal on behalf of your countryman, and ask that you transmit it to him with our compliments and regards."

Mr. Rohrbach responded as follows: "Thank you most sincerely, in the name of Mr. Brandenberger. I feel very happy that this year again The Franklin Institute has awarded a medal to one of my countrymen. It shall indeed be a very great pleasure for me to forward the medal to Mr. Brandenberger."

To Dr. William Francis Giauque, University of California, Berkeley, California. Mr. Richard H. Oppermann, sponsor.

The President called upon Mr. Oppermann.

Mr. Oppermann: "The Board of Managers of The Franklin Institute, upon recommendation of its Committee on Science and the Arts, has voted a Cresson gold medal to Dr. William Francis Giauque, of the University of California, 'In consideration of his outstanding contributions made to our scientific knowledge in the attainment of temperature approaching within one-fourth of one degree of the absolute zero and of his systematic observance and investigation of various substances at these low temperatures.'

"Unfortunately, Dr. Giauque was unable to be with us today to receive his medal in person. I therefore ask you, Mr. President, to see that this medal is conveyed to Dr. Giauque, together with the citation of the award."

The President responded as follows: "The Medal shall be forwarded to Dr. Giauque with a letter, expressing our great

disappointment at his inability to be with us, to allow us to honor him personally."

To Dr. Ernest Orlando Lawrence, Director, Radiation Laboratory, University of California, Berkeley, California. Mr. E. L. Forstall, sponsor.

The President called upon Mr. Forstall.

Mr. Forstall: "The Board of Managers of The Franklin Institute, in accepting the recommendation of its Committee on Science and the Arts, has awarded an Elliott Cresson gold medal to Dr. E. O. Lawrence, Director, Radiation Laboratory, University of California, Berkeley, California, 'In consideration of his development of the cyclotron, an apparatus for accelerating ions which embodies a high degree of technical skill and is of material use in extending the knowledge of nuclear physics.'

"Inasmuch as Dr. Lawrence has found it impossible to be with us, I request you, Mr. President, to have the medal, together with the citation of the award which accompanies it, forwarded to him in due time."

The President responded as follows: "The Coast has claimed four of our outstanding awards today. You will notice that two of our Medalists are from the California Institute of Technology and two from the University of California. We in the East are proud to pay tribute to the outstanding and important work being done in the field of science by our co-workers in the West."

AWARD OF THE FRANKLIN MEDALS.

To Dr. Robert Andrews Millikan, Director, Norman Bridge Laboratory of Physics, California Institute of Technology, Pasadena, California. Dr. James Barnes, sponsor.

The President called upon Dr. Barnes.

Dr. Barnes: "Mr. President, the Board of Managers of The Franklin Institute on the recommendation of its Committee on Science and the Arts is unanimously of the opinion that the two Franklin Medals be awarded this year as follows:

"One to—

"Dr. Robert Andrews Millikan—'in recognition of his isolation and measurement of the fundamental unit of electricity, the electron; the photoelectric determination of the

constant of radiation, Planck's constant; the extension of the ultra-violet spectrum by two octaves to join the spectrum of soft X-rays; and the study of the nature and properties of a very penetrating radiation of cosmic origin.'

"Dr. Millikan was born in Morrison, Illinois, in 1868. His collegiate education was obtained at Oberlin. He then went to Columbia University where in 1895 he earned the degree of Doctor of Philosophy. The following year he received an appointment in the Physics Department of the University of Chicago, where he remained for twenty-five years. It was in his laboratory there that he measured to a very high degree of accuracy the charge on an electron by observing the velocities of a charged droplet of oil as it captured ions during its rise and fall in the space between two parallel electrically charged plates. It was there also that he determined the potential necessary to stop the emission of electrons from metallic surfaces when illuminated by radiations of various frequencies. From the results obtained he derived Planck's constant—probably the most important constant in modern science.

"In 1921 he became the Director of the Norman Bridge Laboratory of Physics of the California Institute of Technology and has devoted most of his time during the past sixteen years to the study of cosmic rays. His apparatus for this study has gone all over the earth from the bottoms of deep lakes to the tops of high mountains. Recently he has sent it into the stratosphere and it is this important phase of the work that we are to hear about in his paper today.

"On account of his brilliant and valuable experimental work he has been the recipient of many medals and honors, including the Edison, Hughes and Faraday Medals and the Nobel Prize.

"He is now on a lecture tour in Europe.

"Mr. President: I express on behalf of all of us our keen regret that Dr. Millikan is unable to be with us today and ask you, sir, to confer on him, in absentia, the Franklin Medal and Certificate of Honorary Membership in The Franklin Institute and to hand them to our Secretary to be forwarded to Dr. Millikan. I present the Secretary of The Franklin Institute, Mr. Henry Butler Allen."

The President then presented the medal as follows: "Mr. Secretary, I commission you to forward to Dr. Millikan without delay this Franklin Medal and Certificate of Honorary Membership which accompanies."

The Secretary said: "Dr. Millikan's lecture engagements abroad, made over a year ago, have kept him from being with us today. He has assured us, however, that he is deeply touched by this valued recognition of his life's work."

To Dr. Peter Debye, Director, Kaiser Wilhelm Institute für Physik, Berlin, Germany. Dr. James Barnes, sponsor.

The President called upon Dr. Barnes.

Dr. Barnes: "Mr. President, the other Franklin Medal is awarded to—

"Dr. Peter Debye—'in recognition of his fundamental conception and masterly development of the theory that molecules of many substances possess permanent dipole moments—a theory of great value in stimulating a vast amount of fruitful research on the electrical properties of insulators, his extension and generalization of Einstein's theory of specific heats of solids, and his work in collaboration with Hückle on a theory of the thermodynamic properties of electrolytic solutions—work upon which the whole modern theory of electrolytes is based.'

"Dr. Debye was born in Maastricht, Holland, in 1884. He studied at the Universities of Aix and Munich where in 1909 he received the degree of Doctor of Philosophy. He has been a very successful teacher and investigator at the Universities of Zürich, Utrecht and Göttingen and he is at present Director of The Kaiser Wilhelm Institut für Physik in Berlin.

"In addition to his outstanding contributions in the fields of physics and physical chemistry, as stated in the above citation, it is of much interest to note that in the realm of X-rays he and Scherer invented the powdered crystal method of analysis about the same time as Hull did independently in Schenectady. He also calculated by means of the quantum theory the changes in the frequencies of X-rays when scattered by collision with electrons. Debye, however, did not publish his work until shortly after Compton had made his experimental verification of the effect in Chicago.

"The list of Debye's honors is a long one including the Rumford Medal of the Royal Society and the Nobel Prize. The President of Harvard University recently conferred upon him the honorary degree of Doctor of Science with the remark 'A large-hearted physicist who gladly lends the chemist a helping hand by elucidating the electrical properties of matter.'

"Mr. President, again I have to express our sincere regret that this distinguished scientist is unable to be present today. However, the Netherland's Chargé d'Affaires has done us the honor of coming here from Washington to receive on behalf of Dr. Debye the Franklin Medal and Certificate of Honorary Membership. We highly appreciate this courtesy.

"Mr. President, I have the pleasure of presenting to you Count van Rechteren Limpurg, Netherlands Chargé d'Affaires, Washington, D. C."

The President then presented the medal as follows: "The man whom you represent today has earned a distinguished place for himself in the realm of science. We delight to do him honor. May I add, also, that we consider it a privilege and an honor to have you with us? It must be very heartening for the men who have unselfishly devoted their lives to science to know that the officials of their country recognize their great achievements and willingly cooperate in public acclaim and honor to such genius.

"It is my privilege as President of The Franklin Institute to hand to you the Franklin Medal, together with a certificate of Honorary Membership in this old society. May we ask that you forward them to Dr. Debye in the diplomatic pouch? We shall be very grateful for this additional service on your part."

Count van Rechteren replied as follows: "Mr. President, it is a great honor for me to represent here my distinguished countryman, Professor Debye, and I thank you and members of the Board of The Franklin Institute on his behalf for the great honor you pay to him in awarding him this Franklin medal, which is one of the highest awards in the scientific world.

"It is a special pleasure for me to represent him, for I had the honor of meeting him in Stockholm when he received the

Nobel Prize. I know how deeply he regrets that he is unable to be here today. He is very hard at work at the Kaiser Wilhelm Institute in Berlin. He would have loved to meet here the great scientists of your country and you would have enjoyed him. He has a charming personality.

"In this case I must say Professor Debye's achievements have also been taken part in by other countries. He has worked for the whole world, and the whole world may be proud of him. Nevertheless, his mother country takes an especial pride in him. I will take care of this medal and these documents and will see that they reach him through the diplomatic pouch."

The President then said: "On the program we were to have read at this time an original paper prepared for this meeting by Dr. Millikan, entitled 'Exploring the Stratosphere for new Electrical Effects.'[1] This paper was to have been read by Dr. Anderson. Unfortunately the paper, which was written by Dr. Millikan in Europe, has not yet reached us. As you already know, Dr. Anderson, who was to have read the paper has been delayed in the West; therefore, the paper which was not received will not be read by Dr. Anderson, who is unhappily not here. I must refer you to the JOURNAL OF THE FRANKLIN INSTITUTE where this paper will be published in its entirety when it is received.*

"The next gentleman to be called upon has for many years had long and close association with the medalist whose paper he will read. He has worked since 1923 in the scientific fields developed by Dr. Debye, our other Franklin Medalist. He has worked with Dr. Debye in his laboratory at Princeton University. Dr. Smyth, will you please read Dr. Debye's

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[1] See p. 145.

* Dr. Robert A. Millikan, who was unable to be present at the Medal Day exercises because of absence in Europe, was kind enough to stop in Philadelphia, Friday, June 25, on his way home to California from Europe, in order to receive from the Secretary of the Institute the Franklin Medal, which had been presented to him in absentia on May 19.

A small meeting was held in the Board of Managers' room when the medal was handed to him by Mr. Allen. Dr. Millikan delivered a few remarks regarding his work and his trip abroad. From the Institute, Dr. Millikan was taken to the Radio Station where he gave, on a national broadcast, abstracts of his paper which had been prepared for the Medal Day Meeting.

paper prepared for this meeting on 'Structure in Electrolytic Solutions.'" [2]

After the reading of the papers the meeting was adjourned with an invitation by the President to attend the dinner which was to be held the same evening.

MEDAL DAY DINNER.

Wednesday Evening, May 19, 1937.

Nearly four hundred members of The Franklin Institute together with friends of the medalists and honored guests gathered together in Franklin Hall at a dinner given to pay tribute to the men who had been awarded medals by the Institute in the afternoon.

Mr. Staples, the President, acted as toastmaster. He called upon several of the medalists who responded by giving short, interesting talks on the work for which they had just been honored.

Later the program was turned over to Mr. Guy Marriner, Associate Director of Music, of The Franklin Institute, who presented an excellent musical program including selections on the glassychord, an instrument used in Franklin's time. Selections were also given on the oscillion, a new scientific musical instrument developed in the Bartol Laboratories of The Franklin Institute. The music which was played was rendered as examples to illustrate Mr. Marriner's talk on Franklin's interest in music.

After this delightful program, the President called upon Mr. Allen, Secretary, who gave a concise and highly enlightening account of the progress of the Institute during the past year. He also touched upon the activities for the coming year, especially the Dedication Program for May 1938.

The Honorable George Wharton Pepper then spoke briefly regarding the future of The Franklin Institute and pointed out the opportunity for service which could be rendered to the Institute by its members during the coming year, especially after the dedication of the entire building next May, when it will be known as—The National Memorial to Benjamin Franklin.

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[2] See p. 135.

NOTES FROM THE BARTOL RESEARCH FOUNDATION.

NEUTRONS AND OTHER HEAVY PARTICLES IN COSMIC RADIATION OF THE STRATOSPHERE.*

BY

L. H. RUMBAUGH and G. L. LOCHER.

Three sets of Imperial Process Plates, to which the technique of Blau [1] was adapted, were sent to the stratosphere inside the gondola of Explorer II, on the National Geographic Society—Army Air Corps flight of November 1935, to register the tracks of any heavy particles of either primary or secondary origin which may occur in the cosmic radiation of the upper atmosphere. 17 plates (1700 cm.^{2}), in a flat nitrogen-filled rubber bag, were covered with materials about 1 cm. thick, representing 20 elements: H, Li, Be, B, C, N, O, F, Na, Mg, Al, Si, S, Cl, K, Ca, Br, Cd, I, and Pb. 15 plates (1800 cm.^{2}), without covering materials, were packed in two separate boxes of thin wood. These plates remained at 1/2 meter, water-equivalent, below the top of the atmosphere for about 2 hours.

Microscopic examination of 70 cm.^{2} of the emulsions under paraffin, aluminum, lead, carbon, and without covering, for α and H tracks at angles between 0° and 45° with the plane of the emulsion shows: (1) no α-particle tracks in plates not covered with materials, other than those tracks originating in radioactive contamination; (2) 4.5 ± 1 proton tracks per cm.^{2} in paraffin-covered plates, but only 0.8 ± 0.4 per cm.^{2} in emulsions covered with lead and with carbon, *so that these protons are evidently recoils from neutron collisions.* In addition, there is evidence that a small number of α-particles and possibly protons occur as secondaries in plates covered with aluminum.

* Reprinted from the *Physical Review*, **49**, 855 (1936).

[1] M. Blau, *J. de phys. et rad.* (*VII*), **5**, 49 (1934); M. Blau and H. Wambacher, *Akad. Wiss. Wien, Ber.*, **134**, 285 (1934).

The radioactive background of the room in which the plates were prepared and developed is low, as measured with an unshielded G–M counter.

All plates examined are compared with control plates of similar sensitive life, covered with the identical materials used with the stratosphere plates. The plates used as controls were originally prepared for the intended flight of July, 1935, and were later left on Pike's Peak (14,000 ft. elevation) for one month. The paraffin-covered plates from Pike's Peak show only 2 proton tracks in 6 cm.^{2} of emulsion, as compared with 27 on an equivalent area of stratosphere plates. Although the possibility of a terrestrial neutron source cannot be entirely eliminated, the foregoing constitutes good evidence that the neutron recoil tracks were produced in the stratosphere, and that the intensity of these neutrons at 6 meters of water below the top of the atmosphere is not more than 0.0005 times as great as at 1/2 meter.

Since the recoil tracks in the emulsion represent only a fraction of the total ranges of the protons, it is difficult to assign an average energy to the neutrons producing them. If one assumes neutrons of one energy uniformly distributed in angle, the number of proton recoils of maximum range R_0 having ranges between R and $R + dR$ is given by $dn = -A\, dR/R_0^{2/3}R^{1/3}$. Application of this formula to the distribution of lengths of proton tracks visible under paraffin, or to the relative numbers of proton tracks produced under paraffin and without paraffin, sets a rough lower limit of 6 MEV for the mean energy of the incident neutrons. To a rough approximation, the number of protons appearing below 1 cm. of paraffin is proportional to the total energy of traversing neutrons. Hence, the direct energy in the primary cosmic radiation of this region of the stratosphere, attributable to neutrons, is calculated to be 1.2 MEV per cm.^{2} per sec. Although probable error cannot be computed, this value is believed to be in error by not more than a factor of 3. The maximum amount of *indirect* energy which could be released by atmospheric transformations would appear from a process similar to the hypothetical one: $N^{14} + n^1 \rightarrow N^{15} + h\nu$, where $h\nu \sim 9$ MEV. Consequently the maximum possible contribution of neutrons, by both direct and indirect processes,

can be of little significance compared with the total cosmic-ray ionization, unless slow neutrons are present in much greater numbers than the distribution of lengths of observable proton recoil tracks indicates.

If these neutrons are primary constituents of cosmic radiation, as the present evidence indicates, the free neutron must be comparatively stable, despite its high mass.[2] Further, the presence of such neutrons suggests that the primary cosmic radiation has been associated with considerable quantities of matter, and should contain considerable gamma-radiation.

The suggestion that primary cosmic radiation at high altitudes contains a strong component of α-particles whose effects are conspicuous at about 1 meter of water,[3] is inconsistent with our observations. From the counting rates obtained with coincidence counter telescopes during the same flight in which the plates were carried aloft,[4] it is calculated that 2×10^5 primary α-particles would have traversed the emulsion examined, if 1/3 of the counter discharges were produced by α-particles. On the assumption that the apparent absorption coefficient for such α-particles is 0.6 per meter of water, and that the plates record α-particles whose energies have been reduced to 100 MEV or less, at least 200 of these particles should have produced observable tracks, whereas none were found. This result is not in conflict with that recently reported by Wilkins and St. Helens,[5] since their tracks are all nearly parallel and came from the horizontal direction; this almost certainly excludes the possibility that their tracks were produced by primary particles. Moreover, the absence of observable primary α-particles cannot be explained by their disappearance through nuclear collisions, since, for a nuclear cross section of 10^{-25} cm.^{2}, 0.67 of all α-particles suffer no nuclear collisions in passing through 1 meter of water-equivalent of atmosphere. The nuclear cross

[2] M. L. Oliphant, *Nature*, **137**, 396 (1936).

[3] A. H. Compton, *Rev. Sci. Inst.*, **7**, 71 (1936).

[4] W. F. G. Swann, G. L. Locher and W. E. Danforth, reported by W. F. G. Swann at the Washington meeting, Am. Phys. Soc., May 1936; *Phys. Rev.*, **49**, 890A (1936).

[5] T. R. Wilkins and H. St. Helens, *Phys. Rev.*, **49**, 403 (1936).

section for α-particles of energies equal to the potential barrier of nitrogen is 10^{-25} cm.^{2} or less, and varies inversely as the velocity for α-particles of greater energies, so most of the suggested primary α-particles [3] would have retained their identity to the end of their range.

A SEARCH FOR PROTONS IN THE PRIMARY COSMIC-RAY BEAM.*

BY

C. G. MONTGOMERY, D. D. MONTGOMERY, W. E. RAMSEY and W. F. G. SWANN.

It has been suggested that a large proportion of the cosmic rays found at sea level are protons. Now a charged particle is characterized by the fact that its ionization increases enormously towards the end of its range, so that, in the case of protons and alpha-particles large and measurable spurts of ionization should be produced in relatively short distances by those rays which are ending their journeys. If r is the distance from the end of the range to the point where the ionization per centimeter of path is σ, then, the fraction of the rays which, passing through a length l of a vessel containing gas at pressure p, produce therein spurts of ions greater in number than $lp\sigma$, is $(1 - e^{-\mu r})$, or approximately, μr, where μ is the absorption coefficient of the radiation concerned. The assignment of a lower limit to the spurts which can be measured determines σ, and so r, through the aid of Bethe's theory; and, it becomes possible to calculate how many such spurts should be observed if the rays are protons. In an experiment based upon the foregoing principles spurts above an assigned size (7.2×10^4 ion pairs in one experiment, and 3.9×10^4 ion pairs in another experiment) produced in a small ionization chamber were measured. To eliminate alpha-particles the chamber was divided into two halves by horizontal partition, and only spurts occurring simultaneously in both halves were counted. Spurts produced by "showers" were recognized and eliminated by suitably arranged Geiger counters. A conservative interpre-

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* An abstract of a paper published in full in the *Physical Review*, **50**, 403 (1936).

tation of the results gives an upper limit for the number of protons present as five per cent. of the total number of cosmic rays at sea level, or 12 per cent. of the intensity of the hard component if Compton's estimate of the absorption coefficient and intensity of the hard component be used. If Millikan's values are adopted our estimate of the upper limit is six per cent.

THE DEPENDENCE OF BURST PRODUCTION UPON ATOMIC NUMBER.*

BY

C. G. MONTGOMERY and D. D. MONTGOMERY.

In previous communications [1] we have suggested that the rate of occurrence, RdN, of cosmic-ray bursts having a number of ionizing rays between N and $N + dN$, may be represented over a large range of burst sizes by the expression

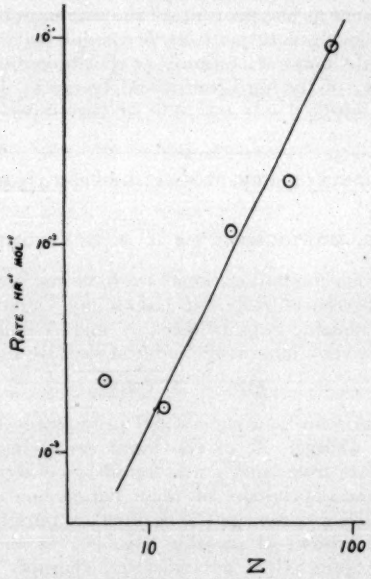
$$RdN = A/N^s dN, \qquad (1)$$

where A and s are parameters and presumably functions of the atomic number, Z, of the burst producing substance. For the bursts from lead, s was found to be about 3.2. To determine the dependence of these parameters upon Z, we have made observations on the numbers of bursts originating in small thicknesses of paraffin, Mg, Fe, Sn and Pb. The bursts were detected in an ionization chamber which consisted of three spherical steel chambers, placed at the corners of a triangle. Each chamber had a diameter of three inches, a wall thickness of a millimeter, and was filled with argon to a pressure of 300 lb. per square inch. A vacuum tube electrometer with photographic recording was employed. The rate of occurrence of bursts greater than 1.6×10^5 ion pairs was determined for each substance. The number of bursts occurring when no material was over the chambers was also measured, and subtracted from the observations taken with the burst producing material present. The rate of occurrence of bursts per atom of the producing material was found to be proportional to the square of the atomic number. The

* Reprinted from the *Physical Review*, **50**, 490 (1936).

[1] C. G. Montgomery and D. D. Montgomery, *Phys. Rev.*, **48**, 786 (1935); **48**, 969 (1935).

FIG. 1.



Rate of production of bursts as a function of atomic number.

results are illustrated in Fig. 1. Through the point for lead in this figure a line with a slope corresponding to a Z^2 variation has been drawn. It fits the other points satisfactorily with the possible exception of the observations on paraffin. This substance produces so few bursts, however, that it is questionable whether any significance should be attached to this apparent exception.

A similar result has been obtained for bursts of different ranges of sizes by other observers. B. Rossi [2] measured the rates of occurrence of small showers from Pb, Fe and Al by means of Geiger-Müller counters. H. Nie [3] has recently made observations upon very large bursts in an ionization

[2] B. Rossi, *Zeits. f. Physik*, **82**, 151 (1933).
[3] H. Nie, *Zeits. f. Physik*, **99**, 787 (1936).

chamber over which were placed these same three substances. Both these sets of observations are as well satisfied by a Z^2 law of variation as the observations reported here upon bursts of an intermediate size. Thus there is good evidence that expression (1) above may be written so as to contain the dependence upon atomic number explicitly as

$$RdN = BZ^2/N^s dN,$$

where B and s are independent of Z.

We may draw two conclusions of significance from this. First, the simple variation with Z^2 suggests that the fields of the nuclei of the burst-producing materials, rather than their particular nuclear structures, are of prime importance, and that it is quite probable that the nuclei remain intact under the impact of the cosmic rays. Second, the picture of a burst being built up by a successive doubling of the number of electrons by the mechanism of pair formation (with or without intermediary photons) is inconsistent with the observed Z^2 variation. Since the probability of each act of pair production, or of the production of intermediary photons, is proportional to Z^2, we should expect the probability of the composite process to vary with a much higher power of Z. We do know that some sort of building up process [4] is involved in the formation of bursts. The experiments here reported, however, seem to show definitely that this building up is not by pair formation, but must involve the simultaneous production of a large number of rays.

The authors are indebted to Professor W. F. G. Swann for much useful advice and helpful encouragement.

ÜBER KOINZIDENZEN VON ULTRASTRAHLUNGSSTÖSSEN.*

BY

C. G. MONTGOMERY and D. D. MONTGOMERY.

Vor kurzer Zeit hat Nie Versuche über die Absorption der Partikel von Ultrastrahlungsstößen mitgeteilt.[1] Nie kommt

[4] C. G. Montgomery, D. D. Montgomery and W. F. G. Swann, *Phys. Rev.*, **47**, 512 (1935).

* Reprinted from *Zeits. f. Phys.*, **102**, 534 (1936).

[1] Heinz Nie, *ZS. f. Phys.*, **99**, 776 (1936).

zu dem Schluß, daß die „mittlere Reichweite" der Stoßkorpuskeln 5 cm. Blei ist. Dieser Wert scheint nicht ganz mit den Messungen der Verfasser [2] übereinzustimmen, welche eine etwas längere Reichweite andeuten. Diese Unstimmigkeit scheint nicht in den Messungen selbst, sondern eher in der Weise ihrer Behandlung zu liegen.

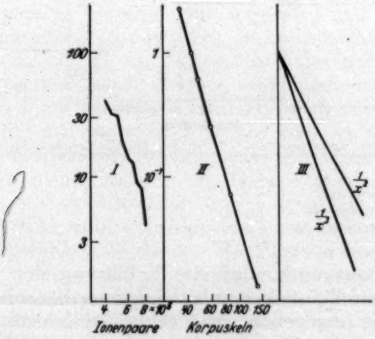
Nie gebraucht zwei Kammern, die eine über der anderen. Über der oberen befindet sich ein Auslöser und zwischen den Kammern ein Absorptionsmittel. Nie mißt die Prozentigkeit der Stöße in der oberen Kammer, welche von Stößen in der unteren Kammer begleitet sind, als Funktion der Dicke des Absorptionsmittels. Er stellt seine Meßergebnisse durch ein Exponentialgesetz, $e^{-\mu x}$ dar, und findet die „mittlere Reichweite" $1/\mu$ der Stoßkorpuskeln zu 5 cm. Blei. Zur Rechtfertigung dieses Verfahrens führt er frühere Messungen [3] an, um zu beweisen, daß die Häufigkeiten des Vorkommens der Stöße ungefähr im ungekehrten Verhältnis wie die Quadrate ihrer Größe stehen. Daher ist die Häufigkeit der Stöße, die größer als eine angegebene Größe sind, umgekehrt proportional zu der angegebenen Größe. Wenn nun das Absorptionsmittel die Größe eines Stoßes auf dem Wege von der oberen zur unteren Kammer zu $1/n$ seiner ursprünglichen Größe verkleinert, so haben die Stöße in der oberen Kammer, die größer sind als die kleinsten in der unteren Kammer gemessenen Größen, die n-mal größer sind als diese kleinste Größe. Diese Stöße kommen aber mit einer Häufigkeit von $1/n$-tel der Häufigkeit der kleinsten Größe in der oberen Kammer vor und der Bruchteil der Stöße in der oberen Kammer, welche gleichzeitige Stöße in der unteren Kammer haben, ist $1/n$.

Jedoch sind unsere Messungen über die Häufigkeitsverteilung der Stöße nicht gut durch eine umgekehrte Quadratregel darstellbar. Sie wären genauer durch eine umgekehrte Kubusabweichung darzustellen. Dieses ist in der Tat der Fall für die von Nie gemachten Angaben und wird in Fig. 1 bewiesen. Wenn man annimmt, daß die umgekehrte Kubusregel richtig ist, dann muß die Exponentialfunktion, um die „mittlere Reichweite" zu bestimmen, an den Quadratwurzeln der Prozentigkeiten der Koinzidenzen zwischen den Kammern

[2] C. G. Montgomery und D. D. Montgomery, *Phys. Rev.*, **49**, 705 (1936).
[3] Heinz Nie, *ZS. f. Phys.*, **99**, 453 (1936).

betrachtet werden und nicht an den Prozentigkeiten selbst. Hieraus würde sich eine „mittlere Reichweite" länger als die verzeichneten 5 cm. ergeben. Jedoch in unseren Experimenten und vielleicht auch in denen von Nie stimmen die Häufigkeitsverteilungskurven für die gleichzeitigen Stöße in der oberen und in der unteren Kammer in der Form nicht überein und es ist schwierig, den richtigen Exponenten für die Verteilungsfunktion $\frac{1}{x}$ zu wählen. Wenn man die umgekehrte Kubusregel annimmt, so können die Ergebnisse von

FIG. 1.

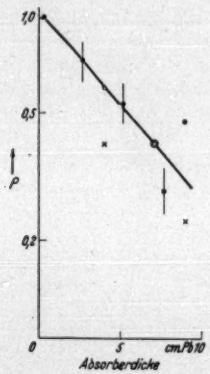


Kurve I: Stossgrössenverteilung bei Fe, H. Nie [4] (Fig. 7, S. 466). Kurve II: Stossgrossenverteilungen bei Fe, C. G. Montgomery und D. D. Montgomery. Kurve III: Umgekehrte Quadrat- und Kubus-Regeln.

Nie und die unseren dargestellt werden wie in Fig. 2. Es wird darauf aufmerksam gemacht, daß die zwei Meßreihen wesentlich übereinstimmen und eine „mittlere Reichweite" von 8 oder 9 cm. andeuten. Die Angaben sind nicht genau genug, um den Kurvenabfall mit der Dicke des Absorptionsmittels entweder als exponentiell oder als linear festzustellen. Es ist vielleicht interessant, darauf aufmerksam zu machen, daß eine „mittlere Reichweite" von bedeutend mehr als 5 cm. mit der Entdeckung von Nie, daß das Maximum der Auslösungskurve der Stöße unterhalb 5 cm. Blei liegt, nicht unverträglich ist.

[4] Heinz Nie, *ZS. f. Phys.*, **99**, 453 (1936).

FIG. 2.



Die Absorption der Stosskorpuskeln. P ist die Durchschlagswahrscheinlichkeit einer Korpuskel.
× H. Nie.[5]
⊙ H. Nie, neu berechnet.
◎ Autoren,[6] erste Methode.
● Autoren,[6] zweite Methode.

Wir bemerken noch, daß die Erklärung der schnellen Zunahme der Stoßhäufigkeit mit der atmosphärischen Höhe, wie sie von Nie angegeben wird, grundsätzlich mit der von Swann [7] angedeuteten identisch ist.

THE HEAVY PARTICLE COMPONENT OF THE COSMIC RADIATION.*

BY

C. G. MONTGOMERY and D. D. MONTGOMERY.

In a recent paper by the above title,[1] Brode, MacPherson and Starr have published a number of cloud chamber photographs of heavy particles which are probably protons. They

[5] Heinz Nie, ebenda, **99**, 776 (1936).
[6] C. G. Montgomery und D. D. Montgomery, *Phys. Rev.*, **49**, 705 (1936).
[7] W. F. G. Swann, *Phys. Rev.*, **48**, 641 (1935).
* Reprinted from the *Physical Review*, **50**, 975 (1936).
[1] R. B. Brode, H. G. MacPherson and M. A. Starr, *Phys. Rev.*, **50**, 581 (1936).

conclude their paper with the statement that "It is now, however, not possible to say that the failure to observe heavy particles in the cosmic radiation in a cloud chamber is evidence against the existence of primary protons." This conclusion depends upon the fact that it is only near the end of the range of the proton that one may expect to find it in a condition such as to produce observable tracks. However, in a recent paper by W. F. G. Swann [2] the theory of this matter was developed and it was shown how one can utilize such knowledge as we have to find how many observable particles might be expected in terms of the number of rays passing through the apparatus per second. In a further paper by the writers in conjunction with W. E. Ramsey and W. F. G. Swann,[3] experiments were reported in which actual measurements were made on the bursts of ionization in an ionization chamber with the resultant conclusion that not more than 10 per cent. of the intensity of the hard component, or more than 5 per cent. of the total number of cosmic rays at sea level, can consist of primary protons.

Now, these same considerations are, of course, applicable to the experiment of Brode, MacPherson and Starr. If, in fact, we assume that the hard component of the cosmic radiation consists of primary protons, then the fraction of these protons which will end their paths within a given distance R is simply μR, where μ is the coefficient of absorption of the radiation. If the relation between the range of a proton and its specific ionization is known, we can find R for a proton which will have a given specific ionization, and so compute the number of particles having a specific ionization greater than this, which we would expect to find in the cloud chamber photographs. Since it is difficult to estimate the age of a track which occurred before the discharge of the counter actuating the cloud chamber, we shall confine our attention to those heavy particles which set off the counters. Brode, MacPherson and Starr found, out of a total of 8500 counter discharges, 7 particles having specific ionization

[2] W. F. G. Swann, *Phys. Rev.*, **49**, 478 (1936).

[3] C. G. Montgomery, D. D. Montgomery, W. E. Ramsey and W. F. G. Swann, *Phys. Rev.*, **50**, 403 (1936).

between two and five times that of an electron, and 7 having between 5 and 20 times the electronic ionization. Let us take for μ the value of 0.08 per meter of water, and assume 0.4 as the fraction of the sea-level cosmic-ray intensity which is the hard component.[4] The range of a proton of specific ionization five times that of an electron (160 ion pairs/cm.) may be taken from Bethe's theoretical values as 1430 meters of air. Hence we should expect, in 8500 rays, 510 protons having at least this ionization. This expected number is considerably smaller than the observed one, and we can, in fact, conclude from these calculations that an upper limit of 1.4 per cent. of the hard component of the cosmic radiation can be primary protons. There is considerable uncertainty, it is true, that the range of protons of this high energy (about 3×10^8 ev.) is given correctly by Bethe's expression, and it is for this reason that no corresponding estimate can be made from the observations concerning the particles having smaller specific ionization. We therefore should place upon the numerical value of the upper limit here calculated only the significance that it is much smaller than is required by a theory of cosmic radiation which ascribes the hard component to primary protons. As has been pointed out before, experiments of this nature cannot eliminate the possibility of primary protons whose effects are produced chiefly through the agency of their secondaries.

Perhaps the weakest point in the foregoing argument lies in the fact that it is necessary to assume a relation between the range and specific ionization of protons which is not yet verified by experiment. However, we have to realize that it is only in respect of such uncertainty that our experiments and those of Brode, MacPherson and Starr fail to give definite evidence against the existence of primary protons in appreciable amounts in the observed cosmic radiation.

[4] A. H. Compton, *Rev. Sci. Inst.*, 7, 71 (1936).

NOTES FROM THE NATIONAL BUREAU OF STANDARDS.*

REVISION OF NATIONAL ELECTRICAL SAFETY CODE.

The fourth edition of the National Electrical Safety Code was completed in 1926 and was approved by the American Standards Association as an American Standard, November 15, 1927. It was revised under ASA procedure by two separate sectional committees, one dealing primarily with Parts 1 and 3 (station and utilization equipment) and the other with Parts 2 and 4 (line construction and operating rules). Part 5 dealing with radio, received attention from both committees. The first committee consisted of 43 members and the latter of 55.

Revision of this Code has now been instituted through the activities of a single sectional committee, all but one of whom were present or were represented at the first meeting of the new committee which was held at the Bureau on May 24. Five technical committees were organized to deal with separate parts of the Code and to consider the various proposals for revision which have been suggested. Anyone having suggestions for improvement of the Code should file them immediately with the Bureau.

Provision has been made for representation upon the technical committees of those organizations which may be concerned with certain sections of the Code and which are not represented upon the main committee.

The following officers were elected by the committee:

Chairman, Morton G. Lloyd, National Bureau of Standards.
Vice-Chairman, C. B. Hayden, Public Service Commission of Wisconsin.
Secretary, A. B. Campbell, Edison Electric Institute.

During the past ten years new practices have developed among the electrical utilities and in the applications of electric energy. Among the new things with which it has

* Communicated by the Director.

been suggested that the Code should deal is the subject of electric fences.

ARC AND SPARK SPECTRA OF LUTECIUM.

The chemical elements known as the rare-earth group are characterized by nearly identical chemical properties which prevent their complete separation or purification by chemical means. As a consequence, their emission spectra are not accurately known, and misidentification of spectra has led to the mistaken discovery of "new" elements. The purest samples of each rare earth are almost invariably contaminated by closely related ones, but by simultaneous study of the spectra of all these, the spectra can be sorted. The spectra of three of the rare earths, thulium, ytterbium, and lutecium, have been under investigation at the Bureau for some years and a new description of conventional arc and spark spectra of lutecium is now made public. This description (RP1008 by William F. Meggers and Bourdon F. Scribner in the July number of the *Journal of Research*) consists of wave-length measurements and intensity estimates of 650 spectral lines scattered throughout the ultraviolet, visible, and infra-red. Furthermore, the lines have been sorted into four groups characteristic of lutecium oxide molecules, neutral lutecium atoms, singly and doubly ionized atoms. Besides providing reliable data for the spectroscopic identification of lutecium, these facts should serve as a basis for further study of interesting features of the various spectra.

DYNAMIC CALIBRATION OF TESTING MACHINES.

The errors of the indicated loads of testing machines used to determine the mechanical properties of engineering materials are usually determined by dead weights, proving levers, or elastic calibrating devices. Each of these methods requires constant or slowly increasing test loads while simultaneous readings of the testing machine and calibrating device are taken. Testing machines, however, are often used to load specimens continuously to failure at a given rate of loading. The additional errors, due to rate of loading,

of six testing machines comprising four types widely used in this country have been determined by Bruce Wilson and Carl Johnson of the Bureau's engineering mechanics section, using a special elastic calibrating device, for rates of loading up to 50,000 lb./min. The testing machines calibrated included one beam and poise, screw-driven machine; two pendulum, hydraulic machines; one spring, hydraulic machine; and two Bourdon-tube, hydraulic machines.

The additional errors of the indicated loads of these machines, due to rate of loading, at rates currently used in testing, exceeded in several cases the tolerance of ± 1 percent. which is specified for such machines. These errors, therefore, cannot, in general, be neglected when determining the rates of loading to be used in materials testing.

For all machines which showed an effect, except the beam and poise, screw-driven machine, the indicated load was less than the applied load. For the beam and poise, screw-driven machine, the indicated load was greater than the applied load.

The results of these tests which are reported in the *Journal of Research* for July (RP1009), although they cannot be used to correct the indicated loads of other testing machines of the same types because of small inherent differences in the weighing systems and slight differences of adjustment, are useful in that they indicate the magnitude of the errors to be expected.

WICK TEST FOR EFFLORESCENCE OF BUILDING BRICK.

At the 1937 meeting of the American Society for Testing Materials there was presented a paper, "The Wick Test for Efflorescence of Building Brick," which described the test devised by John W. McBurney and Douglas E. Parsons, and used at the Bureau for estimating the tendency of building bricks to effloresce. The test consists in standing a whole brick on end in ½ inch of distilled water for 5 days and then drying in an oven at 105° to 110° C. The brick is thereafter compared with an untested specimen and the amount of efflorescence, determined by visual inspection, is reported on a scale consisting of six classifications or grades, described as follows:

(0) None. No observable difference in the appearance of a brick after test and before.
(1) Trace. Efflorescence barely distinguishable by careful comparison.
(2) Slight. Observable. Not sufficient efflorescence to affect materially the appearance when viewed at a distance of approximately 6 feet.
(3) Moderate. Distinct coating, but the original color of the brick distinguishable under the efflorescence.
(4) Considerable. The original color masked by the efflorescence.
(5) Abundant. Efflorescence in such quantity that it may be brushed off readily.

In the *Journal of Research* for July (RP1015) data are given for comparing the results of the wick test on individual bricks and the amounts of efflorescence on masonry panels built from the same grades of brick. These panels were exposed to the weather in Washington, D. C.

The results of the tests and comparisons showed that:

(1) If considerable efflorescence appeared on bricks in the 5-day wick test, masonry panels built of bricks of the same brand showed an objectionable (moderate or more) amount of efflorescence.

(2) If the efflorescence on bricks in the wick test was only a trace or less, most of the masonry panels built from the same brand of bricks showed only a slight (or less) amount of efflorescence.

(3) Soluble salts from mortar appeared to have caused efflorescence on some of the panels.

RELATION OF PORE SIZE OF BRICKS TO THEIR RESISTANCE TO DISINTEGRATION BY FREEZING.

In a study of pore structure and its relation to the resistance of structural clay products to disintegration by weathering, under investigation by R. T. Stull and P. V. Johnson of the Heavy Clay Products Section, ten bricks made from shale by the stiff-mud process were immersed in water for 48 hours at room temperature, placed on edge in $\frac{1}{4}$ inch of water, and subjected to repeated freezings and thawings. Seven of the

bricks have failed and three still appear to be sound. Analysis of the data for the bricks which have failed indicated that the number of freezing and thawing cycles was, in general, inversely proportional to the ratio value "R" and directly proportional to the mean pore diameter "d" of the specimen (calculated according to the Poiseuille formula). This relation is represented by the equation:

$$C = K\frac{d}{R},$$

in which C = number of freezing and thawing cycles at which the specimens failed,
d = average pore diameter, in microns,
R = the value of W/V,
V = total per cent. volume of open or active pores,
K, a constant = 45.34 for the kind of brick tested.

Pore size appears to exercise an influence on the resistance of bricks to failure by freezing as well as does the pore volume available for relief of expansion during ice formation. This is due to the fact that the smaller the pore diameter the greater is the resistance to movement of ice within the pores during freezing. In the table, the C_1 values were determined experimentally and the C_2 values calculated.

[1] Specimen.	Values in Equation.				
	d.	R.	C_1.	C_2.	$(C_1 - C_2)$.
E-3	1.20	0.72	79	76	+ 3
E-5	1.30	.63	92	94	− 2
E-1	1.36	.77	86	80	+ 6
E-2	1.38	.75	82	83	− 1
E-7	1.44	.61	105	107	− 2
E-6	1.48	.59	103	114	−11
E-4	1.54	.67	107	104	+ 3

[1] Arranged in sequence of average pore diameter.

For a well-made brick of uniform grain structure and comparatively free from flaws, the number of cycles of freezing and thawing to cause failure may vary as much as ± 5 per cent. Poorly made bricks and bricks made by the soft-mud process may be lacking in uniform structure and fre-

quently contain "air bubbles," pebbles, and cracks. The number of freezing and thawing cycles at failure of such bricks may vary as much as ± 20 per cent. Thus it is seen (with the exception of specimen E-6) that the differences between the experimental and calculated cycles ($C_1 - C_2$) are comparatively small.

When a specimen fails, it generally shows a ragged, dull, stony fracture. Specimen E-6, of smallest "R" value and second largest pore diameter "d" of the seven specimens, failed much earlier than it normally should (11 cycles below the calculated value) due to the fact that it contained a smooth, glossy surfaced fire crack triangular in shape and about ¾ square inch in area through which the specimen broke.

The three specimens which have not failed at this writing have the largest average pore diameters, namely, 1.66, 2.14, and 2.22 microns and the smallest R values of 0.53, 0.52, and 0.44, respectively. Specimen E-3, of smallest average pore diameter, failed at the lowest number of cycles (79) and E-4, of largest average pore diameter, failed at the highest number of cycles (107).

ACID RESISTANCE OF PORCELAIN ENAMELS.

In Technical News Bulletin 232 (August, 1936), there appeared an item indicating that this Bureau was engaged in developing a test for acid resistance of enamels which would merit adoption as standard. Preliminary results on the research test were given, in which loss of gloss, as determined quantitatively, was taken as a measure of the degree of acid attack.

Since that report the method has been further developed by W. N. Harrison and L. Shartsis. Also, a system of classification for commercial purposes, which calls for a minimum of special equipment, has been evolved. The entire system of tests has now been adopted as a tentative standard by the Technical Research Section of the Porcelain Enamel Institute, and a pamphlet describing it was released by that organization on May 6, 1937.

Two types of treatment are provided: One for articles to be used at room temperature and one for cooking utensils. The former treatment consists of partial immersion of the

sample, under specified conditions, in a 10 per cent. solution of citric acid, simulating lemon juice, for 15 minutes. The treatment for cooking utensils consists of bringing the specimen for 30 minutes into contact with a boiling water solution containing 1.5 per cent. citric acid and 1.5 per cent. malic acid, simulating juice of the more acidic berries and fruits other than lemons.

The system of grading is the same for both treatments. The dividing line between acid-resisting and non-acid-resisting grades is determined as follows:

"Several marks extending across both treated and protected areas shall be made with a No. 1 lead pencil under firm pressure, . . . and the marks rubbed with a cloth which shall have been dipped in water and tightly twisted to eliminate excess water. . . . If the marks over the treated area are definitely more difficult to remove than over the protected area, the specimen fails in this test; otherwise it passes."

A still higher degree of acid resistance is recognized, in which no effect whatsoever can be seen by visual inspection, nor by a test similar to that described above, except that a dry cloth which acts as a more sensitive indicator than the wet cloth, is used for rubbing.

Also, three degrees of resistance to acid attack among non-acid-resisting specimens are recognized. In the most resistant of these three classes a good gloss is retained on the treated area. In the next lower class a definite but not a complete loss of gloss is in evidence, and in the poorest grade the treated area has lost all gloss and become entirely "flat."

GASES IN SOME OPTICAL AND OTHER GLASSES.

It is a well established fact that, when heated to a high temperature in vacuum, practically all ordinary glass evolves gases, including water vapor, carbon dioxide, and oxygen. A knowledge of the amounts and kinds of gas dissolved in some glasses has assisted manufacturers in reducing the quantity of seeds (small bubbles) in those glasses.

Although there are few, if any, seeds in the better grades of window glass and in some of the optical crown glasses

(borosilicate crowns and light crowns), those containing barium (such as the light barium crowns) are usually "seedy," and it was thought that a study of the gases dissolved in the barium crowns might lead to a method for eliminating seeds.

Accordingly, the gases in samples of these glasses were determined, and it was found that the amount of water vapor in all samples was, in general, about 25 ml. per 100 grams of glass, but the amounts of the other gases varied considerably. The gases, other than water vapor in the borosilicate and light barium crowns, never exceeded 2 ml. per 100 grams of glass, the light crown yielded about 4 ml. and the window glasses about 40 ml. The vigorous mechanical stirring incident to the manufacture of optical glass probably explains the small amount of gas found in it, as compared with that obtained from the window glasses, which are not stirred.

Since the quantity of gas obtained from the "seedy" light barium crown was small and about the same or only slightly greater than that obtained from the "seedless" optical glasses, and was decidedly less than from the relatively seedless window glass, it was concluded that the gases dissolved in the light barium crown have no bearing on the prevalence of seeds in the latter.

This study is reported in detail in RP1014 by Clarence Hahner, George Q. Voigt, and Alfred N. Finn, in the July number of the *Journal of Research*.

THE FRANKLIN INSTITUTE.

LIBRARY NOTES.

The library is open for consultation daily from 9 o'clock A.M. until 5 o'clock P.M. and Saturdays 9 A.M. until noon. 571 readers made use of its facilities during the twenty-six days of June.

RECENT ADDITIONS.

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FORSYTHE, W. E. Measurement of Radiant Energy. First Edition. 1937.

HAAS, ARTHUR. The World of Atoms. Twelve Non-Mathematical Lectures. Second Edition Enlarged and Revised. Translated by George B. Welch with the Use of the Translation of the First Edition by Horace S. Uhler. 1937.

HERZBERG, GERHARD. Atomic Spectra and Atomic Structure. Translated with the Cooperation of the Author by J. W. T. Spinks. 1937. Prentice-Hall Physics Series.

UBBELOHDE, A. R. An Introduction to Modern Thermodynamical Principles. 1937.

BOOK REVIEWS.

ATOMIC STRUCTURE OF MINERALS, by W. L. Bragg. 292 pages, illustrations, plates, 15 × 23 cms. Ithaca, N. Y., Cornell University Press, 1937. Price $3.75.

The subject of this book is becoming increasingly popular from a practical standpoint having to do with many fields of activity. It is one that is within the spotlight of modern research and investigation not only for the results recorded but in the method of obtaining the results.

This book was written by one well qualified to do the work. The author is Langworthy Professor of Physics in the Victoria University of Manchester and the book was written during his visit to Cornell University as Baker Non-resident Professor. That he has presented here a book of valuable information is very evident.

There are three introductory chapters dealing with the geometry of crystal patterns, analysis of crystals by X-rays giving various methods, and a treatment

on the general principles of mineral structures. Following these there are thirteen chapters which contain a systematic description by families of mineral structures that have so far been determined. While many structures have not yet been determined, including those of some common minerals such as tourmaline and epidote, it has been possible to make a representative survey, as the general features of all the important families are now known. The book contains a discussion of the relationships between the structures found and the physical and chemical characteristics of the minerals. Unit cell and space group data are tabulated for each structure described and there is sufficient information in the diagrams of the structures to permit the construction of three dimensional models.

The book is written in an easy-to-read manner. There are many illustrations that aid materially in understanding. An index makes it very useful for reference.

For chemists, mineralogists, physicists, as well as others technically inclined along the lines of the subject, this book can be recommended. It is a welcome addition to the literature.

R. H. OPPERMANN.

PRELUDE TO CHEMISTRY, by John Read. 328 pages, 16 × 24 cms. New York, The Macmillan Company, 1937. Price $5.00.

Between the covers of this book there is told a very fascinating story. The reader is taken back and through the early ages, the ages when man began to grope for more knowledge about which he had difficulty in defining. For alchemy itself had many definitions, and, as this work shows after a search and study of great magnitude and proportions, there is disclosed an amazing width of horizon which is included in the term.

The author takes us into the dim past of Egypt and China. We wander through the Graeco-Egyptian era, the Islamic era, the European era and the era of Phlogiston. The literature of alchemy is very carefully examined and there are given examples of alchemical manuscripts, the Emerald table of Hermes and Hylozoistic conceptions in alchemy, among a great many others. An entire chapter is devoted to the Philosopher's Stone, its origin and nature of the quest, the Elixir of Life, other virtues of the stone, preparations of the stone, etc. This is especially interesting.

It is stated by the author that some years ago the work of Daniel Stolcius' extremely rare Viridarium Chymicum, or "Pleasure Garden of Chymistry," fell into his hands, and it is due to this, in a sense, that the present book was written. The last four chapters form an immediate outcome of the work of interpreting and tracing the origins of the 107 emblematic engravings contained in Stolcius' little volume. These are The Golden Tripod, The Mighty King, A Musical Alchemist and The Gardens of Hermes.

As to just what was alchemy, this work shows it was something more than an ancient art which gave rise after long centuries to the modern science of chemistry. It was a complex and indefinite aggregation of chemistry, philosophy, religion, occultism, astrology, magic, mythology, and many other constituents. It was a strange blend of logical thinking and mystical dreaming, of sound observation and wild superstition, of natural and moral ideas, of objective facts and subjective conclusions.

The book contains a large number of illustrations, reproductions of old and valuable originals. This in itself, together with accompanying explanations,

makes not only for interest, but brings before every reader the results of a great amount of work that otherwise would, only with much difficulty if at all possible, be available.

A reader of this book cannot help but absorb some of the romance of man's early search for truth. It should bring refreshment to the chemist and should add interest to the subject by contributing a human side to it.

R. H. OPPERMANN.

MARCONI, THE MAN AND HIS WIRELESS, by Orrin E. Dunlap, Jr. 360 pages, plates 15 × 22 cms. New York, The Macmillan Company, 1937. Price $3.50.

Just what is the secret that covers all synonymous words and phrases would be very difficult to determine, for there are many variations and reasonings. But in the case of the words "Marconi" and "Wireless" the answer is obvious. Guglielmo Marconi is the man who made wireless telegraphy a practical and useful aid to mankind.

This book is a biography of Marconi. It tells of his birth, the conditions of the world, what the world was thinking and the problems of the time. Marconi's education, his inherited traits and his introduction to Hertzian waves are all told, as well as the almost insurmountable difficulties and problems, both scientific and of human skepticism and even direct opposition, that the young man had to overcome. The development of the apparatus for transmission and reception, its introduction in England, France, and America, all comprise Part I of the book covering the period 1874–1899.

Next, the first transatlantic signal, the letter "s," was received on Dec. 12, 1901. The present-day radio enthusiast can gain some appreciation of the difficulties of reception at that time by the explanation that there was no calibrated dial receiver to facilitate adjusting the circuit to a specific wave-length. Neither was the wave of the transmitter across the ocean known. There was no device to measure it. Only through guesswork and tuning over broad areas was the correct wave finally found. Wireless telegraphy from this time on progressed much more rapidly.

But all was not smooth sailing. Further experimentation and further studies for the perfecting of what was yet but crude and inefficient apparatus were necessary. Legal battles began on validity of patents. Through it all Marconi kept working, defending, and developing. The first big test of wireless in the saving of lives at sea came with the crash of the *S. S. Republic* and *Florida* in a fog off Sandy Hook. That it played an invaluable part is a matter of history.

Then came the *Titanic* disaster. The story of wireless in this case will never die. During the Great War, Marconi also played a part not only with his wireless but in other capacities as well. The period after the war became known as the dawn of the radio era and Marconi bought and equipped a yacht to be used as a floating laboratory where he could experiment to his heart's content.

The author of this book, an experienced writer, has here presented a work that should be read by everyone. It is a colorful story of true adventure in the life of a great man. It is adaptable to youth, for it is filled with action, fires the imagination, and provides inspiration. For the older reader it is informative and interesting.

R. H. OPPERMANN.

MAN IN A CHEMICAL WORLD, THE SERVICE OF CHEMICAL INDUSTRY, by A. Cressy Morrison. 292 pages, illustrations, 16 × 22.5 cms. New York, Charles Scribner's Sons, 1937. Price $3.00.

If you are just an ordinary individual with average intelligence not engaged in a chemical industry you have, no doubt, heard many times of the contributions of various industries to your necessities, comforts, and conveniences. Even if you are engaged in an activity associated with a chemical industry, there is little likelihood of your ever dreaming of the broad scope that this industry covers in making your life pleasant and in supplying you with things unheard of only a short time ago.

This matter of industrial contribution to human welfare is taken too lightly in these times and the reason is probably due to the fact that most of us have gotten into the habit of taking new inventions and developments for granted, to the extreme point of being disappointed when something hasn't been conceived to overcome the little twist in our everyday lives that makes for monotony. In other words, the average of us does not appreciate the practical applications of man's knowledge.

This is the reason why the book "Man in a Chemical World" should be read. It belongs to that class of books that translates the language of the technical to that of the layman so that he may easily read and understand. It is an outgrowth of the celebration of the three hundredth anniversary of the birth of the chemical industry in the United States.

As the title signifies, the book is a story of how much a part chemistry plays in modern life. It reveals how utterly dependent man is on the chemical industries not only for the necessities and luxuries of life, but also for his very existence. It is a proud record of the accomplishments of man in the role of creator.

One feature of the book is outstanding. That is, it explains in a remarkably clear way the interdependencies and interrelationships of various industries on one another—how the product of one supplies a necessary need for another and how through this great maze of exchange a completed work comes for the benefit of all of us.

The book is for everyone to read and it is so written that everyone can read it.

R. H. OPPERMANN.

THE NEWER ALCHEMY, by Lord Rutherford. 67 pages, illustrations, plates, 12.5 × 19 cms. New York, The Macmillan Company, 1937. Price $1.50.

The alchemists of old are probably best known for their most spectacular efforts, those of the transmutation of matter, the search for the Philosopher's Stone to transmute one element into another, and particularly to produce gold and silver from the common metals. The belief that this could be done was carried through for ages so that an interesting and fascinating story was made.

The Newer Alchemy is just as interesting and fascinating a story. It is contained in this little book of sixty-seven pages. The scientist of today with much more knowledge and equipment is forging ahead into the realms of the unknown and accomplishing what only yesterday was unheard of. It is shown that the dream of the old alchemist has been partly realized. It is possible by modern methods to produce exceedingly minute quantities of gold, but only by the transmutation of an even more costly element, platinum. While this in itself is a most

spectacular achievement, the general knowledge being gathered with relation to the constitution of matter and its transformation may bring on wonders in this age of science never dreamed of before.

The author, a well known scientist, has based this little work on the Henry Sidgwick Memorial Lecture delivered at Newnham College, Cambridge, November 1936. It is an interesting story complete with interesting illustrations.

R. H. OPPERMANN.

ELECTRICITY AND MAGNETISM, an Introduction to the Mathematical Theory, by A. S. Ramsey. 267 pages, illustrations, 14 × 22 cms. Cambridge University Press, 1937. Price $3.25.

As the title implies, this book is a text for students just entering the field of the subject. A review of the mathematical prerequisites with which the reader must be familiar in order to be able to understand the contents of the book are given at the beginning. Briefly, this knowledge amounts to little more than some elementary calculus and a few properties of vectors. Following this, the book is divided into ten parts. The first is an introduction to electrostatics with the object to formulate a working hypothesis and build upon it a mathematical theory which will describe correctly the phenomena which take place in an electric field. Then there follows a part on conductors and condensers including Laplace's equation, another on systems of conductors and then another on homogeneous dielectrics and the theory of images.

Magnetism is then taken up, followed by electromagnetism, magnetic induction and induced magnetism, and electromagnetic induction.

The author does not hesitate to intersperse examples through the chapters, and to give solutions of some of them. Diagrams are used throughout the text wherever necessary. The book does not contain a subject index, nevertheless its construction is such that one having followed through its treatment page by page may be able to discount the use of an index for reference at a later time and substitute therefore the table of contents.

Because of its construction and impressive manner of presentation, prospective students as well as teachers of the subject would do well to examine this book.

R. H. OPPERMANN.

THE REACTIONS OF PURE HYDROCARBONS, by Gustav Egloff. 897 pages, illustrations, 15.5 × 23.5 cms. New York, Reinhold Publishing Corp., 1937. Price, $16.75.

This book is an American Chemical Society Monograph and as such it merits the attention of all who are interested in chemical technology, especially workers in the realm of organic chemistry. While it is true that the reactions of pure hydrocarbons have been studied and investigated for many years, it has only been comparatively recently that the subject has received the impetus that has placed it in one of the foremost classes. Hydrocarbons in one state or another are available everywhere in almost unbelievable quantities. Hydrocarbon researches, which have no correlation one with the other, are being carried out in many parts of the world. The purpose of this book is to make available all the work on the reactions of pure hydrocarbons which occur as the result of

thermal, catalytic, photochemical, or electrical treatment with a view of further stimulating interest.

The book is divided so that there are outlined seven distinct hydrocarbon groups. They are paraffins, olefins, acetylenes, aromatics, cycloparaffins and cycloölefins, and terpenes. Reactions in the presence of non-hydrocarbon substances are included only when they act catalytically and the reaction products are hydrocarbons. The effect of acids as catalysts have been omitted except in some cases where it was thought that they were of import to carry out the purposes of the study.

The author and his associates have performed a tremendous amount of work here. They have correlated and explained the work of some 1200 different investigators, originally published in hundreds of different technical journals, government reports and scientific treatises. This includes the patent literature as well, although no attempt is made to include all of the patents relating to reactions of hydrocarbons. Only those are included that have specific bearing on the subject. All references are noted in bibliographies at the end of each part of the book. At the end of the book there appears a very comprehensive subject and author index.

Undoubtedly this book fills a very definite and pressing need. It therefore is a safe prediction that it will be in great demand in many researches in diverse fields of endeavor.

R. H. OPPERMANN.

DISTILLATION, by Joseph Reilly. 118 pages, 11 × 17.5 cms. London, Methuen & Co., Ltd. Price, $1.25.

This is a short monograph of 118 pages issued by the Chemical Publishing Co. for North and South America. In it there is a surprising amount of information on the theoretical and industrial aspects of the subject. The author, well known as an authority on the azeotropic process, has given a fair picture of the present state of the art, including a review of pertinent technical literature and supplementing this with expert knowledge. His work treats on fractionation, production and measurement of low pressure, vacuum fractionation, azeotropic mixtures, distillation in a current of steam, destructive distillation and sublimation. It is extraordinarily well done in presenting the subject in its present day condition and as such should be of interest and value in this particular field.

An index is listed in the table of contents but, due possibly to an error in binding, it is not included. Undoubtedly this would add to the value of the work for quick reference purposes.

R. H. OPPERMANN.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

Report No. 585. Span Load Distribution for Tapered Wings with Partial-Span Flaps, by H. A. Pearson. 18 pages, illustrations, tables, 23 × 29 cms. Washington, Government Printing Office, 1937. Price ten cents.

Tables are given for determining the load distribution of tapered wings with partial-span flaps placed either at the center or at the wing tips. Seventy-two wing-flap combinations, including two aspect ratios, four taper ratios, and nine flap lengths, are included. The distributions for the flapped wing are divided

into two parts, one a zero lift distribution due primarily to the flaps and the other an additional lift distribution due to an angle of attack of the wing as a whole.

Comparisons between theoretical and experimental results for wings indicate that the theory may be used to predict the load distribution with sufficient accuracy for structural purposes.

Simple computing forms are included for determining, by the Lotz method, the theoretical loadings for a combination of any wing with any flap. A discussion of the method is given showing: (1) the effect on the load distribution of increasing the number of harmonics for a wing with partial-span flaps; and (2) the effect of increasing the number of points used across the semispan for a wing of unfair plan form.

Report No. 589. An Analysis of Lateral Stability in Power-Off Flight with Charts for Use in Design, by Charles H. Zimmerman. 22 pages, illustrations, 23 × 29 cms. Washington, Government Printing Office, 1937. Price ten cents.

The aerodynamic and mass factors governing lateral stability are discussed and formulas are given for their estimation. Relatively simple relationships between the governing factors and the resulting stability characteristics are presented. A series of charts is included with which approximate stability characteristics may be rapidly estimated.

The effects of the various governing factors upon the stability characteristics are discussed in detail. It is pointed out that much additional research is necessary both to correlate stability characteristics with riding, flying, and handling qualities and to provide suitable data for accurate estimates of those characteristics of an airplane while it is in the design stage.

Report No. 590. Pressure-Distribution Measurements on an O-2H Airplane in Flight, by H. A. Pearson. 33 pages, illustrations, tables, 23 × 29 cms. Washington, Government Printing Office, 1937. Price fifteen cents.

Results are given of pressure-distribution measurements made over two different horizontal tail surfaces and the right wing cellule, including the slipstream area, of an observation-type biplane. Measurements were also taken of air speed, control-surface positions, control-stick forces, angular velocities, and accelerations during various abrupt maneuvers. These maneuvers consisted of push-downs and pull-ups from level flight, dive pull-outs, and aileron rolls with various thrust conditions.

The results from the pressure-distribution measurements over the wing cellule are given on charts showing the variation of individual rib coefficients with wing coefficients; the data from the tail-surface pressure-distribution measurements are given mainly as total loads and moments. These data are supplemented by time histories of the measured quantities and isometric views of the rib pressure distributions occurring in abrupt maneuvers.

The results indicate that there is little if any dissymmetry of load on the tail due to slipstream rotation and that the up loads may be as much as the down loads. From the results of the wing investigation it was found that the relative efficiency of the wings depended upon the type of maneuver.

Report No. 599. Flight Tests of the Drag and Torque of the Propeller in Terminal-Velocity Dives, by Richard V. Rhode and Henry A. Pearson. 10 pages, illustrations, tables, 23 × 29 cms. Washington, Government Printing Office, 1937. Price ten cents.

The drag and torque of a controllable propeller at various blade-angle settings, and under various diving conditions, were measured by indirect methods on an F6C-4 airplane in flight. The object of these tests was (1) to provide data on which calculations of the terminal velocity with a throttled engine and the accompanying engine speed could be based and (2) to determine the possibility of utilizing the propeller as an air brake to reduce the terminal velocity.

The data obtained were used in the establishment of propeller charts, on the basis of which the terminal velocity and engine speed could be calculated for airplanes whose characteristics fall within the range of these tests. It was found that the propeller reduced the terminal velocity about 11 percent with the normal blade-angle setting of 19.0° and about 35 percent with a 5.5° setting. Indications were that the terminal velocity could be still further reduced by using even lower blade-angle settings. A method is given for the calculation of the terminal velocity with throttled engine and the engine speed.

PUBLICATIONS RECEIVED.

Origins of Clerk Maxwell's Electric Ideas as described in familiar letters to William Thomson, by Sir Joseph Larmor. 56 pages, illustrations, 18 × 26 cms. Cambridge, University Press, 1937. Price, $1.00.

Elasticity, Plasticity, and Structure of Matter, by R. Houwink. 376 pages, plates, diagrams, 14 × 22 cms. New York, the Macmillan Company, 1937. Price, $6.00.

Printing in the Americas, by John Clyde Oswald. 565 pages, illustrations, 17 × 24 cms. New York, The Gregg Publishing Company. Price, $7.50.

Sound, a text book, by Arthur Taber Jones. 450 pages, illustrations, 15 × 22 cms. New York, D. Van Nostrand Company, Inc., 1937. Price, $3.75.

An Outline of Atomic Physics, by members of the Physics staff of the University of Pittsburgh: O. H. Blackwood, Elmer Hutchisson, Thomas H. Osgood, Arthur E. Ruark, W. N. St. Peter, George A. Scott, A. G. Worthing. Second Edition, 414 pages, illustrations, 15 × 23 cms. New York, John Wiley & Sons, Inc., 1937. Price, $3.75.

Zero to Eighty, Being my Lifetime Doings, Reflections, and Invention; also my Journey Around the Moon, by Akkad Pseudoman (Edwin F. Northrup). 283 pages, plates, illustrations, 16 × 24 cms. Princeton, New Jersey, Scientific Publishing Company, 1937. Price, $3.00.

Fundamentals of Engineering Electronics, by William G. Dow. 604 pages, illustrations, 15 × 23 cms. New York, John Wiley & Sons, Inc., 1937. Price, $5.00.

Transactions of the Bose Research Institute Calcutta, Vol. X, 1934–1935, Biological and Physical Researches, by Sir Jagadis Chunder Bose. 240 pages, illustrations, tables, 15 × 23 cms. London, Longmans, Green and Co. Price, 18 shillings.

Canada Department of Mines and Resources. Investigations in Ore Dressing and Metallurgy, January to June, 1936. 186 pages, plates, tables, 16 × 24 cms. Ottawa, J. O. Patenaude, I. S. O., 1937.

Report of Annual Luncheon and First Annual Conference of the Combustion Appliance Makers Association (Solid Fuel), March 16, 1937. 104 pages, 20 × 25 cms. London, Combustion Appliance Makers Association. Price, 2s. 6d.

Bell Telephone Laboratories, Monographs: B-978, Measurement of Distensibility of Organic Finishes, by A. E. Schuh and H. C. Theuerer. 9 pages, illustrations, tables. B-979, An X-Ray Study of Some Linear Polyesters, by C. S. Fuller and C. L. Erickson. 18 pages, illustrations, tables. B-988, Microanalytical Notes—Parts I and II, by Beverly L. Clarke and H. W. Hermance. 13 pages, illustrations. B-989, Study of Magnetic Losses at Low Flux Densities in Permalloy Sheet, by W. B. Ellwood and V. E. Legg. 16 pages, illustrations, tables. B-990, Sound Recording on Magnetic Tape, by C. N. Hickman. 13 pages, illustrations. B-991, Constant Resistance Networks with Applications to Filter Groups, by E. L. Norton. 16 pages, illustrations. B-992, Crosstalk between Coaxial Transmission Lines, by S. A. Schelkunoff and T. M. Odarenko. 21 pages, illustrations. 7 pamphlets, 15×23 cms. New York, Bell Laboratories, 1937.

National Advisory Committee for Aeronautics. Aircraft Circulars: No. 205, The Hafner A. R. III Gyroplane (British), 7 pages, illustrations. No. 207, Baynes Bee Light Airplane (British), A Two-Seat High-Wing Monoplane. 9 pages, illustrations. Technical Notes: No. 599, Charts Expressing the Time, Velocity, and Altitude Relations for an Airplane Diving in a Standard Atmosphere, by H. A. Pearson. 20 pages, illustrations, figures. No. 603, A Preliminary Study of Flame Propagation in a Spark-Ignition Engine, by A. M. Rothrock and R. C. Spencer. 20 pages, illustrations, figures. 4 pamphlets, 20 × 26 cms. Washington, Committee, 1937.

CURRENT TOPICS.

In Davy Jones' Locker.—(*General Electric Review*, Vol. 40, No. 6.) When Captain John D. Craig descends this summer to the wreck of the Lusitania to film the scheduled salvage operations, his equipment will include a battery of the most powerful lamps ever designed for deep sea work. The new lamps, developed by engineers of the General Electric Co., are built to withstand a water pressure of 500 lb. per sq. in., more than three times the pressure encountered around the hull of the vessel, submerged in 312 feet of water off the Irish Coast, where the pressure is 150 lb. per sq. in. Each lamp has a light output of 137,500 lumens. A set of twelve of them will be mounted on a special submarine stage, to floodlight the scene. The intense heat at which the lamps operate would cause them to fail in a few minutes if burned in the open air. Due to the cooling action of the water, however, they will function for 25 hrs. The bulbs, made of special, hard ultra-violet transmitting glass to provide the best possible photographic light, are filled with a mixture of nitrogen and argon, and fitted with special rubber insulation to insure perfect waterproofing.

R. H. O.

Solar Energy and Its Use for Heating Water in California.—The practical utilization of the vast amount of solar energy is not easy. In the past there have been various attempts to do this which were more or less successful. At the present time, however, direct use of solar energy is being made by several thousand solar water heaters in California, according to F. A. Brooks in Bulletin 602 of the University of California, College of Agriculture. Successful use depends, of course on the number of sunshine days. Many different types of solar water heaters have been developed, primarily based on the nature of the hot water demand.

R. H. O.

Power Production from Tropical Vegetable Waste.—XAVER SOEHNER begins a series of articles on this subject in *Engineering*, Vol. CXLIII, No. 3723, in which there is given an account of what has been designed and constructed in the way of suction gas plants. Among the materials used in such plants are included cotton capsules and cotton seed coats, palm nuts, cocoa, brazil nuts, olive husks,

castor oil husks and cake, and sunflower seed husks. All of these, in the air dried condition have a moisture content ranging up to 30 per cent. In general, three systems of gasification are available—1. A rising gas flow, with the production of tar,—2. A descending gas flow with the partial production of unburnt tar,—3. The double flow system giving so-called tarless gasification. The systems consist of a cylindrical chamber, about three quarters filled with the gas making material. The gas offtake is at the top, and the upper layer of the gas making material is known as the drying zone, the next lower layer the zone of distillation, the next the reducing zone, and finally the zone of combustion. This rests upon a grate which is fed by an underblast or overblast of air as the case may be. The gas at the outlet has a temperature of 350 to 450 deg. C. and must be washed clean of particles. It is then suitable for use in internal combustion engines.

R. H. O.

Roof Garden Laboratory for Studying Insects and Soils.—On the roof of its building in Washington D. C., the U. S. Department of Agriculture has completed two glassed-in laboratories for research by scientists who occupy offices below. Studies will be made on insect pests and specially treated soils—work that needs fresh air and sunshine. The characters by which many kinds of insects may be identified are known only for the adult stage. It is impossible to identify the immature stages. When living specimens of grubs or other immature stages belonging to groups that cannot be classified are submitted for identification, it is proposed to cage them so they can complete their development, making adults available for study. After getting specific approval, entomologists and plant quarantine inspectors may forward such insects for identification which will aid in combating insect pests and the enforcement of plant quarantines. Other insects will be studied also, as well as the effects of various substances added to different soils.

R. H. O.

A Projection "Kinescope" and a High Current Electron Gun.—Before the Institute of Radio Engineers recently, DR. V. K. ZWORYKIN and W. H. PAINTER of RCA disclosed recent achievements with new television projection tubes, a result of years of research. Such a tube is about eighteen inches in length and produces an image about $1\frac{1}{2} \times 2\frac{1}{4}$ inches on its fluorescent screen. This is so brilliant that a simple optical system will project it on a large screen. The principal feature of the device is a new type of electron gun, developed by Dr. R. R. Law and others in the RCA

laboratories. The gun is the structure in a television receiving tube which focusses flying electrons into an extremely slender beam. The detailed construction of the new gun calls for specifications so rigid that the idea was nearly discarded as impracticable. A flood of electrons must be regimented into the solid column of a narrow beam, to "paint" the received picture more vividly on the fluorescent screen of the Kinescope. The electrons are "conditioned" for the job by being passed through three metal discs, each having an aperture in its center about the diameter of a pencil lead. Then, they pass through a fourth and last disc, similar to the others, but with an opening too small to pass a human hair. Electrons are made to pour through this tiny opening to the fluorescent screen at the tube's end. The bombardment is so intense that the light produced on the screen of the projection Kinescope may be spread over an area 100 to 400 times greater in a projected picture.

R. H. O.

Vibrating Concrete Pavements Adds 10 Per Cent. to Strength.—Vibrating the concrete in a pavement as it is laid increases the strength 10 per cent. according to a report by the U. S. Bureau of Public Roads or, by vibrating, 10 per cent. less cement can be used and the same strength maintained. Vibrators work on somewhat the same principle as those in giving beauty treatments. The report gives the results of an investigation recently conducted at Arlington, Va. Two hundred and seventy slabs of pavement, each 10 feet wide and 8 feet long, were constructed and tested. Four different types of vibrating equipment were used, their speeds varying from 3600 to 4000 revolutions per minute. Slabs of similar composition were placed and finished by standard methods without vibration. Thus, differences in the strengths and physical properties were directly attributable to vibration. In every instance it was found that vibration increased the strength and density and decreased the amount of "honeycomb," or air pockets. To investigate the effects of vibration further, the quantities of aggregates, cement, and water were varied in slabs finished by the vibration method, and their properties were compared with those of nonvibrated slabs. Slabs 7 and 10 inches thick were placed, and the effects of surface vibration were found to extend entirely through both.

R. H. O.

New Tubes for Ultra-High Frequency Work.—An important step toward the "colonization" of a recently penetrated frontier of radio frequencies was described by W. G. WAGENER of the RCA

laboratories, before the recent convention of the Institute of Radio Engineers. The step relates to the creation of new tubes designed to produce unusually large power on radio wavelengths whose use will provide perhaps thousands of new channels for new radio services. On a wavelength of three meters the water cooled tube can generate 700 watts and on one and a half meters it can supply 500 watts. This tube is so small that its size belies its ability to produce power of this order. It was pointed out however, that the efficiency of the device is due in no small degree to this feature of smallness, since the use of the elements of larger areas would introduce electrical capacity effects that would render it less effective on very short wavelengths. Another advantage which minute size realizes is a short path for the electrons to travel in their flight from the cathode to the plate. This is of prime importance since, when operated on a wavelength of three meters, the electrons within the tube must travel between cathode and plate in one five hundred millionth of a second. In the new device the grid is spaced only six hundredths of an inch from the cathode. A water jacket is used in this tube because the generation of large power by means of tube electrodes of such small size requires the dissipation of considerable heat.

R. H. O.

To Map 350,000 Square Miles of Farm Land from the Air.—Aerial mapping, as a relatively cheap and improved method of determining performance under the Agricultural Conservation Program, will be used on a much broader scale this year than heretofore. The Agricultural Adjustment Administration stated that proposed aerial mapping will, along with areas already being flown, bring the total area to be mapped by the AAA in 1937 to approximately 350,000 square miles in 34 states.

R. H. O.

New Natural Gas Process.—(*Oil and Gas Journal*, Vol. 36, No. 6.) After seven years of laboratory research DR. E. P. SCHOCH, director of the Bureau of Industrial Chemistry, University of Texas, announces discovery of a method of processing natural gas into by-products. The process may be applied at the well or elsewhere. The discovery, as explained by Doctor Schoch, is how to control electric discharges or electric arcs through natural gas, making possible production of a definitely desired product, including carbon black, acetylene and others of commercial importance. Doctor Schoch has a patent pending on the new method and when it is granted will turn it over as a gift to the state of Texas. He said

that by the use of electrical discharges in processing of natural gas into a variety of products the volume of gas valued at $200,000,000 annually, going to waste in Texas, would be saved and converted into wealth many times that amount. Doctor Schoch pictured the possibility of processing plants being established at individual wells in the Panhandle and other parts of the state.

R. H. O.

World's Fair Test Building Resembles Joseph's Coat.—(*Engineering News Record*, Vol. 118, No. 25.) Blocked and patched with multihued designs, a unique test building stands conspicuously on the vast expanse of land on the reclaimed Flushing Meadows that will be the site of the 1939 New York World's Fair. This unique building, whose walls can be made to twist, heave, buckle, sag or otherwise contort at the will of the testing engineer, is a practical laboratory where the merits of various heights of wall coating and different stucco treatments are tried out. Inside the 40 × 60 ft. structure is a complete testing laboratory for further analysis of materials proposed for interiors and exteriors of the 300 proposed buildings. Ground consolidation, wind pressure, fire resistance, stucco layering, weather tightness, stud spacing, paint acceptance, insulation, light refraction, illumination possibilities, ceiling heights, flexibility of material, and economies consistent with temporary building, are a few of the factors governing research as carried on within and without the test building. The building code of the Fair Corporation is, in part, responsible for institution of the test building, since it provides that all walls in all exposition buildings must have at least 1/2 hr. fire resistance.

R. H. O.

High Speed Turbine Generators Meet Modern Requirements.—During the past period of depressed national and world conditions when the need for new equipment of this type for central stations was practically at a standstill, an analysis and study were made in preparation for supplying equipment for modernized stations so as to be able to meet the demand when it arose. The result of this work is reviewed by C. M. LAFFOON, Generator Engineer of the Westinghouse Electric & Mfg. Co., in *The Electric Journal*, Vol. 34, No. 6. It developed that in 1936 there was an immediate need for generator ratings up to 60,000 kva. at 80 to 90 per cent. power factor range. New materials and different design proportions dictated a unit to operate at 3,600 r.p.m., which at this size was beyond any actual experience heretofore encountered. The successful construction of 3,600 r.p.m. generators at these ratings was made

possible by three major accomplishments. They are: (1) The development by the principal steel forging companies of alloy steel forgings with a material improvement in physical characteristics and ductility properties; (2) improvements in both stator and rotor ventilation and a better coördination of design proportions and utilization of materials that increased the output per unit of active materials; (3) the use of hydrogen as the cooling medium to increase the output per unit of materials still further, and to improve the generator efficiency.

R. H. O.

Electrogalvanized Wire Gives Corrosion Defiance.—W. C. FRANK AND W. E. MILLER. (*Electrical World*, Vol. 107, No. 25.) The Bethlehem Steel Co. after eight years of electrochemical and electrometallurgical research has perfected a process from which there is obtained a coated steel wire having physical properties entirely different from any of the zinc coatings so far produced by either the hot-dip galvanizing process or the conventional zinc electroplating process. In the new process the zinc is applied to the surface of the wire by electrodeposition from a bath of purified zinc sulphate solution circulated through electrolytic cells. There is no metallic zinc in the system except that which is deposited out of the solution as virgin metal, spectroscopically pure, creating a tough, ductile and tenacious coating. Current densities are much higher than in previous electroplated galvanizing. While zinc itself is corrodible through atmospheric attack, the purity of this new zinc coating is such that the progress of corrosion is checked after the formation of a very thin film of carbonate or oxide.

R. H. O.

Small-Scale Placer Mines as a Source of Gold, Employment and Livelihood in 1935.—According to a report of a study by members of the Bureau of Mines submitted to the Works Progress Administration, more than 28,000 individuals were engaged in placering at some time during the year 1935, demonstrating that gold diggings are sizable consumers of human effort. The number was twice the labor force required to mine the nation's iron ore in the same year, and this count includes only those miners who made at least one sale to a bullion buyer. An unknown number of others worked but found no gold. For those miners who were recorded as selling some gold, the average number of days worked was 45, the average daily gross income was $1.60, and the average gross earnings for the year were $72. This report shows conclusively the futility of following the suggestion, frequently made in recent years, that large numbers

of people be encouraged to become gold miners as a means of solving the unemployment problem.

R. H. O.

Air Conditioning as a Problem of Water Distribution and Disposal.—A great many are watching the development of the new air conditioning industry. The engineering professions, especially those engaged in refrigeration, and in heating and ventilating, have been concerned with this matter of air conditioning for a considerable time, but it is only during the past few years that the waterworks engineer has awakened to the fact that he is vitally concerned. This is what L. D. GAYTON, City Engineer, Chicago, Ill., stated recently before the Illinois Section of the American Water Works Association. Mr. Gayton reviewed the problem with respect to Chicago and indicated that at the present time the air conditioning equipment installed in the central business district of this city, which equipment uses no water conserving devices, but demands a maximum supply of water for cooling purposes and then wastes this water directly to the sewers, when operated at maximum capacity requires a rate of approximately 35,000,000 gallons of water per day. Within 20 years this demand of water, providing no water conserving devices are installed, may amount to as much as 295,000,000 gallons of water per day. At the present time there is available to the loop area of Chicago sufficient water for at least 10 years to come. However, present sewers in this area are inadequate to take care of maximum use.

R. H. O.

Rubber Expansion Joint Used in Sewage Plant Blower Line.—(*Engineering News Record*, Vol. 118, No. 24.) Provision for expansion and contraction of air blower lines at the new Easterly sewage disposal plant in Cleveland, Ohio, has been made by installing special rubber expansion joints which were designed and made by the F. Goodrich Co. In addition to absorbing movement of the line, due to frequent thermal changes, use of these joints on the blower outlet prevents vibration from being transferred to the distribution line. The blower units are capable of moving 170,000 cu. ft. of air per minute; the largest units have a capacity of 40,000 c.f.m. The intake line on each blower has a suction pressure of 10 in., water gage, and the outlet has a discharge pressure of 7½ lbs.

R. H. O.

Dogs Dried by Gas.—(*Gas Age-Record and Natural Gas*, Vol. 79, No. 13.) Installation of a new gas-heated dog drying cabinet

makes use of a gas appliance innovation in the Hollywood Dog and Cat Hospital of Portland, Ore. By means of this novel use for gas, DR. C. T. NORMAN, the owner and operator of the hospital, who designed the special cabinet, can turn out a washed "puppy" completely dry in 15 minutes. He is able to throw in an application of beneficial health rays for good measure. Gas-heated air is pumped into the drying cabinet from a furnace that also supplies heat for the complete building, and which has a capacity of 2,000 ft. a minute for servicing the two-story stucco building.

R. H. O.

City 1960.—MR. NORMAN BEL GEDDES has designed a model city in which he believes we may all be working in twenty-odd years from now. Illustrations of the model, made under the sponsorship of the Shell oil companies, appear in the *Architectural Forum*, Vol. 67, p. 57. The plan was laid out under the assumptions, that the automobile will, in twenty years, be essentially the same type of carrier that it is today, no provision for autogiros and similar possible developments having been considered, that the city of the future will be larger and not smaller than it is today, and that all land will be completely controlled by the municipality. Obviously, with the predetermined location of skyscrapers, low buildings, parks and super-streets, there would be no place for the type of private initiative which exists in the real estate field today. The model shows a highly concentrated business center whose use of huge towers, widely spaced, would contain a working population of three to five times the present density average in New York, and supporting a total population of perhaps 15,000,000. Seen from above, the city appears as a grid, with blocks 250×500 ft., bounded by streets 80×100 ft. wide. Traffic on these streets would flow at about 20 miles an hour, as compared with present average New York City traffic speed of 6 miles an hour. An average city street has three moving lanes, two parking lanes, and 15 ft. of sidewalk at the sides. The sidewalks are raised a story, providing three more lanes of traffic. Parking and loading take place on the ground floor level of the buildings, thus making available two additional lanes of traffic. These five additional lanes of moving cars increase the street capacity 65 per cent. At ten-block intervals are the arterial highways, 400 ft. in width, and divided according to the speed and character of the traffic.

R. H. O.